8 CELL —THE BASIC UNIT OF LIFE

As observed by Lamarck (1809), *no body can have life if its constituent parts are not formed of cells*. Cell theory further elaborated the role of cells. According to cell theory, all organisms are formed of cells and that new cells develop from pre-existing ones. Study of form, structure and composition of cells is called **cytology**. Branch of biology that deals with various aspects of structure, chemistry, development, genetics and functioning of cells is called **cell biology**. In cell biology, scientists study fundamental processes that are common to all cells and are akin to studying various life processes. Cell biology is, therefore, a unifying subject.

Basic Unit

Cell is a basic unit of life as no living organism can have life without being cellular because cell is a unit of both its structure and function. All life begins as a single cell. A number of organisms are made of single cells. They are called **unicellular** or **acellular**, *e.g.*, *Amoeba, Chlamydomonas, Acetabularia*, bacteria, yeast. Here a single cell is (i) capable of independent existence and (ii) able to perform all the essential functions of life. Anything less than a complete cell can neither lead an independent existence nor perform all the functions of life. A **multicellular organism** is made of many cells. A higher animal or plant contains billions of cells. For example, a newly born human infant has 2×10^{12} cells. The number increases to 100 trillion (100×10^{12} or 10^{14}) cells in the body of 60 kg human being. About 25% (25×10^{12}) of them are found in the blood. A drop of blood contains several million cells. The large sized organisms do not have large sized cells. Instead they possess higher number of cells. In multicellular organisms, cells are **building blocks** of the body or basic units of body structure. Of course, they become specialized for performing different functions. Human body has some 200 types of cells, *e.g.*, erythrocytes, leucocyte types, epithelial cell types, muscle cells, nerve cells, fat cells, cartilage cells, bone cells, connective tissue cells, gland cells, germinal cells, pigment cells, etc. Cells are grouped into tissues, tissues into organs and organs into organ systems. Occurrence of different types of tissues, organs and organ system results in **division of labour** or performance of different functions of the body by specialised structures.

Cells are not only the building blocks of the organisms, they are also the **functional units** of life. Life passes from one generation to the next in the form of cells. The activities of an organism are actually the sum total of activities of its cells. Each cell of the body possesses the same genetic information though mature cells may become specialized to perform specific functions. A new cell always develops by division of a pre-existing cell. Cells are **totipotent**, *i.e.*, a single cell has the ability to form the whole organism. Internally each cell is build up of several organelles. The organelles perform different functions just like the ones carried on by different organ systems of the body. All life activities of the organism are present in miniature form in each and every cell of its body. Thus, cell is a **basic unit of life** and **structural and functional unit of an organism.** It is the **smallest** unit capable of **independent** existence and performing the **essential functions** of life.

Discovery of Cell

Work on the study of cell has continued for more than the last three and a half centuries. It required **microscopes** or instruments with good resolving power and magnification. Techniques like preservation, sectioning, staining and mounting were needed to distinguish various cellular components. Improvement in tools and techniques has continued all this period to enhance our knowledge about the cell.

The first microscope was built by Zacharias Janssen in 1590. It was first modified by Galileo (1610) and then by Robert Hooke (Fig. 8.1). Robert Hooke (1635–1703) was a mathematician and physicist. He developed a new microscope with which he studied the internal structure of a number of plants. His work is famous for the study of cork cells. In 1665, Robert Hooke wrote a book "**Micrographia** : or *Some Physiological Descriptions of Minutae made by magnifying glasses with observations and enquiries there upon.*" The chapter which gave birth to cell biology is "*Observe XVIII : of the schematisme or texture of cork and of the cells and pores of some other such frothy bodies*". He took a piece of cork of spanish oak and prepared thin slice by means of sharp pen knife. A deep planoconcave lens was used for throwing light on cork piece. The latter was observed under the microscope (Fig. 8.1). The piece of cork was found to have a honey comb structure with a number of box like compartments, each having a pore and separated from others by diaphragms (Fig. 8.2). Robert Hooke named the compartments as **cellulae** (singular– cellula) now known as **cells** (Latin *cella* – hollow spaces or compartments). He did not know the significance of these structures and regarded them as passages for conducting fluids. Actually the 'cells' of Hooke were cell walls enclosing spaces left by dead protoplasts. Robert Hooke found that the cells or boxes were not very deep. A cubic inch contained 1259,712,000 cells, a square inch 1,66,400 and one inch strip 1080 cells. The term "cell" is actually a **misnomer** as a living cell is neither hollow nor always covered by a wall.

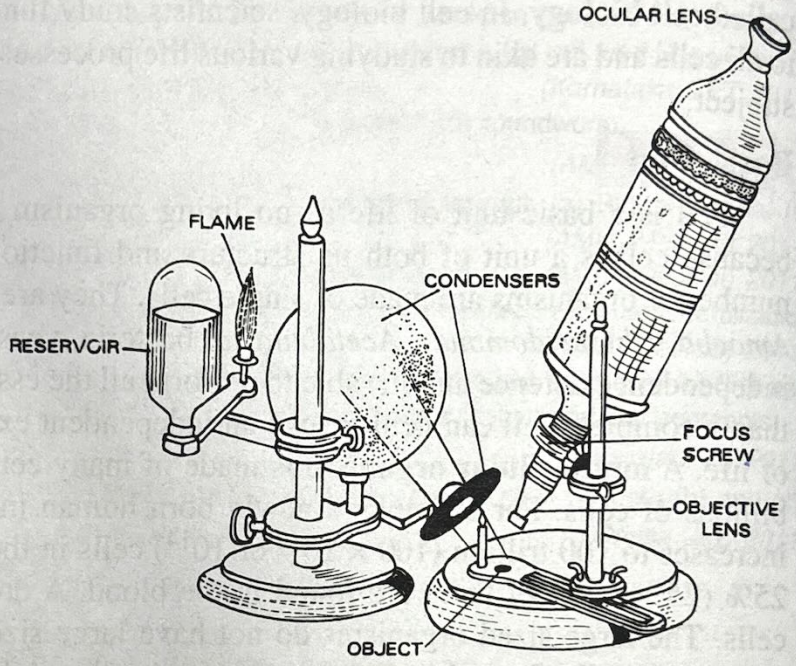

Fig. 8.1. The crude microscope employed by Robert Hooke (1665).

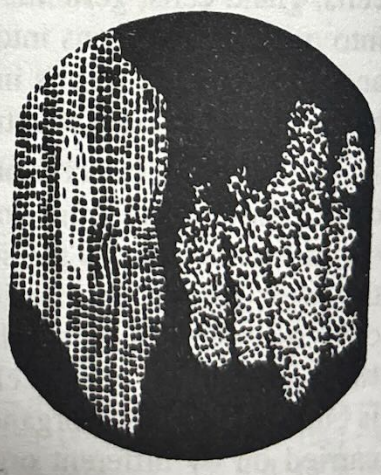

Fig. 8.2. Drawing of cork cells by Robert Hooke (1665).

Cells were also observed prior to Hooke, by Malpighi (1661), who called them saccules and utricles. **Leeuwenhoek** (1673) was first to observe, describe and sketch a free live cell. He observed bacteria, protozoa, spermatozoa, red blood cells, etc. In 1675, Malpighi and in 1682 Grew gave an account of the internal structure of plants but further work on cells was interrupted for more than a century. In the

beginning of nineteenth century it became clear that the bodies of organisms are made of one or more cells. Mirbel (1802) observed that '*plants are formed by membranous cellular tissue.*' Dutrochet (1824) had stated '*all organic tissues are really globular cells of an extreme smallness which are united by cohesion.*' By this time optical microscopy underwent a sort of revolution with the improved quality of lens (Dolland, 1827), development of oil immersion lens, improvement in the design of microscope, microtomy and staining. Robert Brown (1831) discovered the presence of **nucleus** in the cells of orchid root. Living semifluid substance of cells was discovered by Dujardin (1835) and named sarcode. Schleiden (1838) found all plant cells to have similar structure— cell wall, a clear jelly-like substance and a nucleus. Schwann (1838) discovered that animal cells lacked cell wall. Purkinje (1839) and von Mohl (1838, 1846) renamed sarcode or the jelly like substance of the cells as **protoplasm** (Gk. *protos*– first, *plasma*– form). Cell membrane was discovered by Schwann (1838) but was provided with a name by Nageli and Cramer (1855). Soon various organelles were discovered inside the cells. Electron microscope has elaborated our knowledge about cells.

Cell Theory

The theory was jointly put forward by Schleiden and Schwann (1839) in their paper "*Microscope Investigations on the similarity of structure and growth in animals and plants.*" Cell theory states that the bodies of all organisms are made up of cells and their products so that cells are units of both structure and function of living organisms.

Formulation of Cell Theory

Development of cell theory illustrates how scientific methodology operates. It involves observation, hypothesis, formulation of theory and its modification. Observations were started by Malthias Schleiden (1838), a German botanist who examined a large number of plant tissues. He found that all plant tissues were made of one or the other kind of cells. Therefore, he concluded that cells constitute the ultimate units of all plant tissues. Theodore Schwann (1838), a German Zoologist, studied different types of animal tissues including development of embryos. He found that animal cells lack a **cell wall**. Instead they are covered by a membrane. Otherwise cells of both plants and animals are similar. Schwann defined a cell as membrane enlocked, nucleus containing structure. He also proposed a **cell hypothesis** (Schwann, 1838)— *bodies of animals and plants are made of cells and their products.*

Schleiden and Schwann compared their findings, discussed Schwann's hypothesis and formulated the cell theory in their joint paper in 1839. The theory proposed that cells are the units of both structure and function of organisms. However, the proposers of cell theory were not the first to state that organisms are made of cells. Similar statements had already been made by Mirbel (1802), Lamarck (1809) and Dutrochet (1824). Schleiden and Schwann are, however, credited with piecing together their observations and conclusion in formulation of a theory. They did not know the mode of formation of new cells. They believed that new cells developed either spontaneously or by budding of the nucleus. Nageli (1846) disapproved the same. Rudolf Virchow (1855) observed that new cells develop by division of the pre-existing cells— *Omnis cellula e cellula* (theory of cell lineage or common ancestry). The finding gave cell theory its final shape. Louis Pasteur (1862) further proved that life originated from life. Soon Haeckel (1866) established that nucleus stores and transmits hereditary traits. Cell theory was modified accordingly.

Fundamental Features of Cell Theory

Five fundamental observations of the cell theory are:

1. All living organisms are composed of cells and their products.

2. Each cell is made of a small mass of protoplasm containing a nucleus in its inside and a plasma membrane with or without a cell wall on its outside.

3. All cells are basically alike in their chemistry and physiology.

4. Activities of an organism are the sum total of activities and interactions of its constituent cells.

Modern Cell Theory

It is also known as **cell doctrine** or **cell principle**. Modern cell theory states that

1. The bodies of all living beings are made up of cells and their products.

2. Cells are units of structure in the body of living organisms. Every cell is made up of a mass of protoplasm having a nucleus, organelles and a covering membrane.

3. Cells are units of function in living organisms, that is, the activities of an organism are the sum total of the activities of its cells.

4. While a cell can survive independently, its organelles cannot do so.

5. The cells belonging to diverse organisms and different regions of the same organism have a fundamental similarity in their structure, chemical composition and metabolism.

6. Life exists only in cells because all the activities of life are performed by cells.

7. Depending upon specific requirement, the cells get modified, *e.g.*, elongated in muscle and nerve cells, loss of nucleus in RBCs or cytoplasm in outer skin cells.

8. Growth of an organism involves the growth and multiplication of its cells.

9. Genetic information is stored and expressed inside cells.

10. Life passes from one generation to the next in the form of a living cell.

11. New cells arise from pre-existing cells through division. All new cells contain the same amount and degree of genetic information as contained in the parent cell.

12. All the present day cells/organisms have a common ancestry because they are derived from the first cell that evolved on the planet through continuous line of cell generations.

13. Basically the cells are totipotent (*i.e.*, a single cell can give rise to the whole organism) unless and until they have become extremely specialized.

14. No organism, organ or tissue can have activity that is absent in its cells.

Objections

(i) Viruses are acellular and do not have a cellular machinery. Even then they are considered to be organisms.

(ii) In some organisms, the body is not differentiated into cells though it may have numerous nuclei (coenocytes, *e.g., Rhizopus*).

(iii) Protozoans and many thallophytes have a uninucleate differentiated body (*e.g., Acetabularia*) which cannot be divided into cells. They are acellular.

(iv) Bacteria and cyanobacteria do not have nucleus and membrane bound organelles.

(v) RBCs and sieve tube cells continue to live without nucleus.

(vi) Protoplasm is replaced by nonliving materials in the surface cells of skin and cork.

(vii) Schleiden and Schwann did not know the mechanism of cell formation. Schwann believed cells to develop spontaneously like a crystal. Schleiden thought new cells to develop from cytoblast or nucleus.

Significance of Cell Theory. (i) There is a structural similarity in cells belonging to diverse groups of organisms. (ii) All the cells perform similar metabolic activities. (iii) Life

exists only in the form of cells. (iv) Life passes from one generation to the next as cells. (v) All living beings are descendents of a primitive cell that developed on earth as the first eucaryote and prior to that as the first procaryote.

Other Theories

(i) **Protoplasmic Theory** (Max Schultze, 1861). The living matter of an organism is not cell but protoplasm.

(ii) **Organismal Theory** (Sachs, 1874). The body of living being is made up of continuous mass of living matter which is incompletely divided into compartments called cells. The whole organism functions as a single entity.

Surface : Volume Ratio

The factors which set the limit of cell size or volume are :

(i) Nucleo-cytoplasmic or kern-plasma ratio (ratio of nucleus to cytoplasm) which determines the range of control of metabolic activities by nucleus.

(ii) Ability of oxygen and other materials to reach every part of the cell.

(iii) Ability of waste products to pass to the outside.

(iv) Rate of metabolic activity.

(v) Ratio of surface area to the volume of the cell.

Metabolically active cells are usually smaller due to higher nucleocytoplasmic ratio and higher surface volume ratio. The former will allow the nucleus to have better control of metabolic activities while the latter will allow quicker exchange of materials between the cell and its outside environment. Surface volume ratio decreases with the increase in cell size or volume as surface increases by the square of the size while volume increases by the cube of the size. Take three cubic cells which have the surface area of 6 mm^2 (6 × 1 × 1), 24 mm^2 (6 × 2 × 2) and 54 mm^2 (6 × 3 × 3) and a volume of 1 mm^3 (1 × 1 × 1), 8 mm^3 (2 × 2 × 2) and 27 mm^3 (3 × 3 × 3) respectively (Fig. 8.4). The surface to volume ratio in the three would be 6 : 1, 3 : 1 and 2 : 1. Therefore, larger cells have lesser surface volume ratio. They tend to become less efficient. All passive cells like eggs are, therefore, larger in size. All active cells are smaller. If larger cells are to remain active, they are either cylindrical in shape or possess several extensions of the cell membrane. **Microvilli** are one of such developments. They are found in all those cells which are active in absorption. Membrane infoldings also occur in **transfer cells** found in plants in the region of absorption or secretion of nutrients.

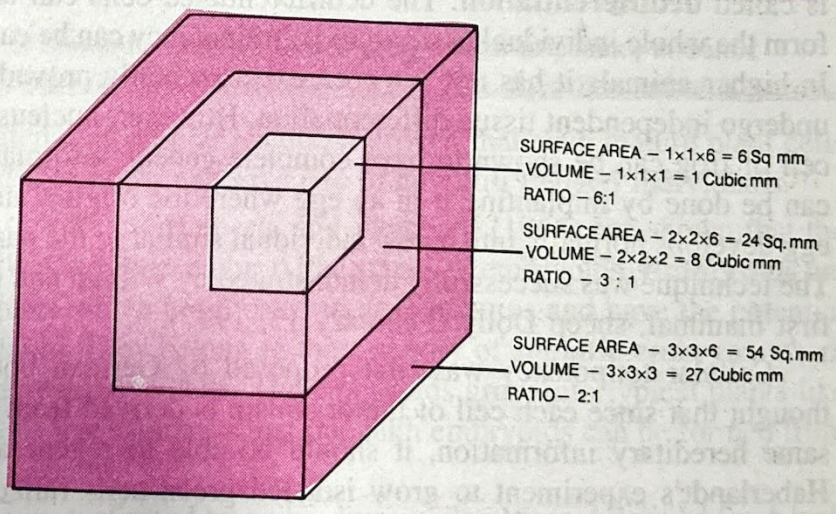

Fig. 8.3. Effect of size on surface area volume ratio.

Types of Cells

A multicellular organism is composed of numerous cells. The cells are of three main types— **undifferentiated** (stem cells), **differentiated** (post-mitotic cells) and **dedifferentiated**.

(a) **Undifferentiated or Stem Cells**. They are unspecialised cells which usually possess the power of division, *e.g.*, stem apical meristem, root apical meristem, vascular cambium, cork cambium, stratum germinativum of skin, germinal epithelium, bone marrow, etc. Zygote is also an undifferentiated cell.

(b) **Differentiated or Post-mitotic Cells**. The cells are specialized to perform specific functions. Differentiation occurs in shape, size, structure and function through an orderly switching on and off of some particular genes of the cells by means of chemicals named as inducers and repressors. It leads to better organisation, division of labour and higher efficiency. Duplication of work is avoided.

(c) **Dedifferentiated Cells**. They are differentiated cells which revert to undifferentiated state to take over the function of division. The process by which they lose their specialization is called **dedifferentiation**. It involves reactivation of certain genes that prevent differentiation, allow limited growth and induce division. Cork cambium of plants is always produced through dedifferentiation. Dedifferentiation helps in healing of wounds, regeneration in animals, or vegetative propagation in plants. Cell culture experiments are based on this dedifferentiation of cells.

Cellular Totipotency

Totipotency (L. *totus*– all, *potens*– powerful) or cellular totipotency is the ability of a living somatic nucleated cell to form the complete organism. Theoretically all somatic cells should be totipotent since they carry the full gene complement of the individual. However, during their maturation the cells undergo differentiation and are unable to return to their undifferentiated status. They, however, do so under special circumstances. The phenomenon is called **dedifferentiation**. The dedifferentiated cells can undergo division and ultimately form the whole individual or a part of it. Totipotency can be easily demonstrated in plant cells. In higher animals it has not yet been experimentally proved. It is because the cells do not undergo independent tissue differentiation. However, nucleus taken from any living somatic cell of frog can be shown to have complete genetic information and hence totipotent. This can be done by implanting it in an egg where the original nucleus has been taken out. The egg develops normally into a new individual similar to the parent which donated the nucleus. The technique was successfully demonstrated by Wilmut and Campbell when they cloned the first mammal, sheep Dolly (February 13, 1997).

Cellular totipotency was first proposed by German botanist Haberlandt in 1902. He thought that since each cell of the organism is derived from fertilized egg and contains the same hereditary information, it should be able to regenerate the whole plant. However, Haberlandt's experiment to grow isolated green cells failed due to lack of nutrients and perfect asepsis. The two defects were removed by White (1932). The scientist successfully grew Tomato roots in culture medium. In 1939, three scientists (White 1939; Gautheret, 1939; Nobecourt, 1939) were independently able to grow callus in tissue culture. **Callus** is unorganised but actively dividing mass of undifferentiated cells. Skoog and Miller (1957) discovered that callus can be made to develop shoots or roots through changing the ratio of hormones (IAA and cytokinin). The phenomenon is called **morphogenesis**. Cellular totipotency was demonstrated for the first time by Steward *et al* (1957) of Cornell University, USA (Fig. 8.4). They took 2 mg pieces from phloem of Carrot roots. These pieces or **explants** were made up of mature nondividing cells. The workers placed these explants in liquid culture medium containing coconut milk. The culture flasks were shaken gently throughout. This caused the cells to separate. The latter remained either isolated or formed small cellular clusters. There was an active growth and division of cells. On the stoppage of shaking, the

cells tended to form clusters. Clusters differentiated and formed initials of roots. When they were transferred to semisolid medium, each developed shoot and gave rise to a plantlet or a small plant. The plantlets were further transferred to earthern pots where typical full fledged plants with conical fleshy roots developed.

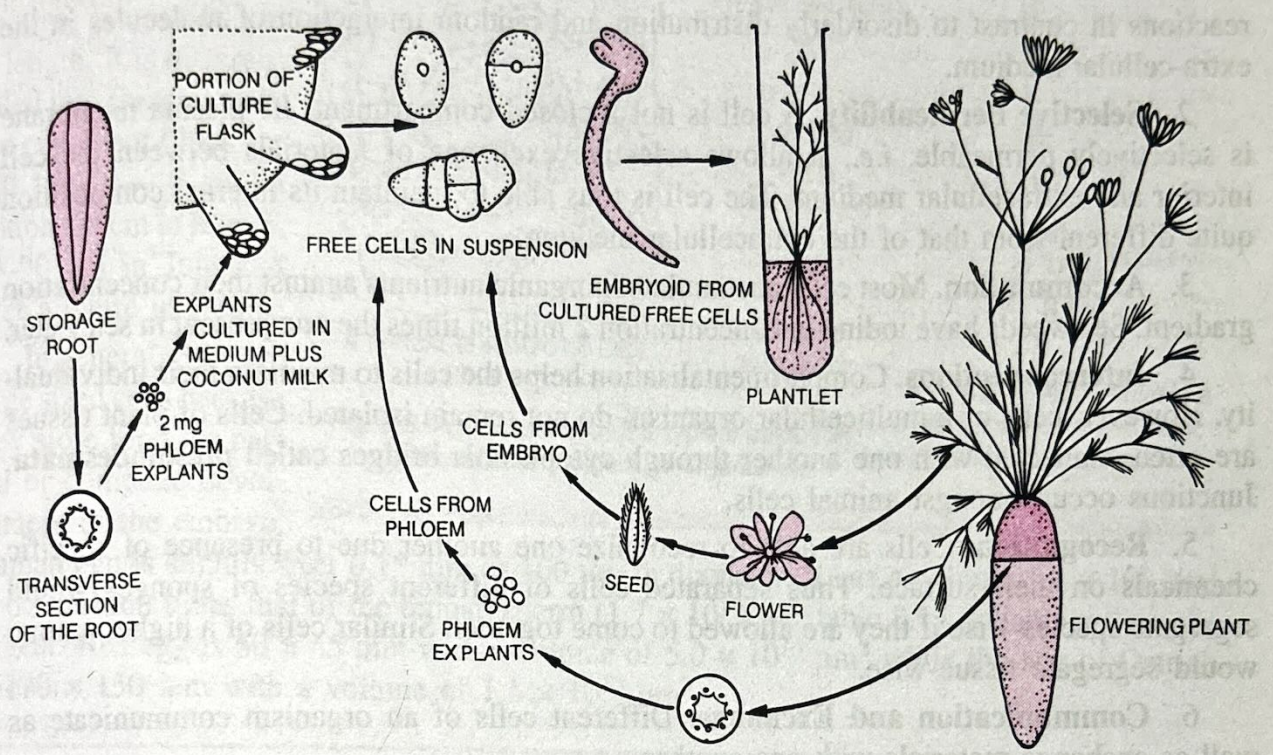

Fig. 8.4. Culture experiment of Steward and co-workers to show cellular totipotency in Carrot.

The experiment was repeated with similar results. It proved that even mature plant cells can dedifferentiate, divide, redifferentiate and give rise to new full fledged individuals.

Further work by Steward (1963) and Halperin and Wetherell (1964) has shown that the separated actively dividing cells often form embryo like stages or embryoids. **Embryoids** are nonzygotic embryo like structures which are formed *in vitro* cultures and have the potential to develop into full fledged plants. They belong to the category of **somatic embryos** where embryos develop from diploid vegetative cells. The embryoids grow into typical plants like normal embryos. Steward (1964) has estimated that one lakh embryoids can be formed from a single Carrot embryo or an explant.

Cellular totipotency has been confirmed by using diverse plant tissues derived from leaf, bud, floral bud, anther, endosperm, nucellus, embryo, stem, root, etc. The method is being extensively used in :

(a) Rapid multiplication of desired plants. (b) Multiplication of rare plants which reproduce through seeds with great difficulty. (c) Embryos which fail to reach maturity. (d) Multiplication of sterile hybrids. (e) Production of virus free plants. (f) Multiplication of products of protoplast fusion. (g) Shorten the period for development of new varieties. (h) Development of resistance to chemicals. (i) Induction and selection of mutants.

Compartmentalization for Cellular Life

Every cell behaves as a compartment because it is completely covered over by a membrane known as plasma membrane or plasmalemma. It may also possess some internal

compartments in the form of membrane lined organelles like mitochondria, plastids, lysosomes, golgi bodies, nucleus, etc. Nonmembranous organelles occur in both procaryotic and eucaryotic cells, *e.g.*, ribosomes.

1. **Separation from Extracellular Medium**. Plasma membrane of the cell segregates its protoplasm from the extracellular medium. As a result, the protoplasm does not mix with the latter. It allows the cell to maintain its chemical pool, orderliness of structure and reactions in contrast to disorderly distribution and random interaction of molecules in the extra-cellular medium.

2. **Selective Permeability.** A cell is not a closed compartment. Its plasma membrane is selectively permeable, *i.e.*, it allows selective exchange of materials between the cell interior and extracellular medium. The cell is thus able to maintain its internal composition quite different from that of the extracellular medium.

3. **Accumulation.** Most cells accumulate inorganic nutrients against their concentration gradient. Sea weeds have iodine in concentration 2 million times the one present in sea water.

4. **Interconnections**. Compartmentalisation helps the cells to maintain their individuality. However, cells of a multicellular organism do not remain isolated. Cells of plant tissues are often connected with one another through cytoplasmic bridges called **plasmodesmata**. Junctions occur amongst animal cells.

5. **Recognition.** Cells are able to recognize one another due to presence of specific chemicals on their surface. Thus separated cells of different species of sponges would segregate species-wise if they are allowed to come together. Similar cells of a higher animal would segregate tissue-wise.

6. **Communication and Exchange**. Different cells of an organism communicate as well as exchange materials with one another.

7. **Intracellular Compartmentalisation**. Membrane lined cell organelles act as intracellular compartments. They allow the cells to separate diverse types of chemical reactions.

Cell— An Open System

An open system is the one which is separated from its surroundings by a boundary that allows transfer of materials and energy across it. Cell is an open system because it receives a number of materials including energy containing nutrients from outside. It liberates energy as heat and sends out excretions.

Cell Size

There is a wide variation in the size shaped and activities of cells. The smallest cells are those of *Mycoplasma*. They have a size of 0.1–0.5 μm. Bacteria measure 3–5 μm in length. Viruses are still smaller. They do not have a cellular structure. The smallest virus has a volume of 7.0×10^{-7} μm^3. The smallest mycoplasma has a volume of 1.0×10^{-3} μm^3 while the smallest bacterium possesses a volume of 2.0×10^{-2} μm^3. Unicellular eucaryotes have a size of 1–1000 μm. Sporozoite of *Plasmodium* is only 2 μm long. Cells of multicellular eucaryotes have a size range of 5–100 μm. Among multicellular organisms, human erythrocytes (RBC) are about 7 μm in diameter. Some lymphocytes are still smaller (6 μm). Cells of kidney, liver, skin and intestine are 20–30 μm in diameter. Muscle and nerve cells are comparatively very large. A striated muscle cell can be 1– 40 mm long and 30–80 μm in thickness. Longest cells of human body are the nerve cells which may reach a length of 90cm.

Amongst plants, large cells occur in many algae. Internodal cells of *Chara* are 1–10 cm in length. *Acetabularia* (Fig. 8.5B), a unicellular alga, is upto 10 cm in length. It is differentiated into rhizoid, stalk and cap. Plant fibres are still longer— 4 cm in Cotton, 55 cm in Ramie, 30–90 cm in Jute and over a metre in Hemp.

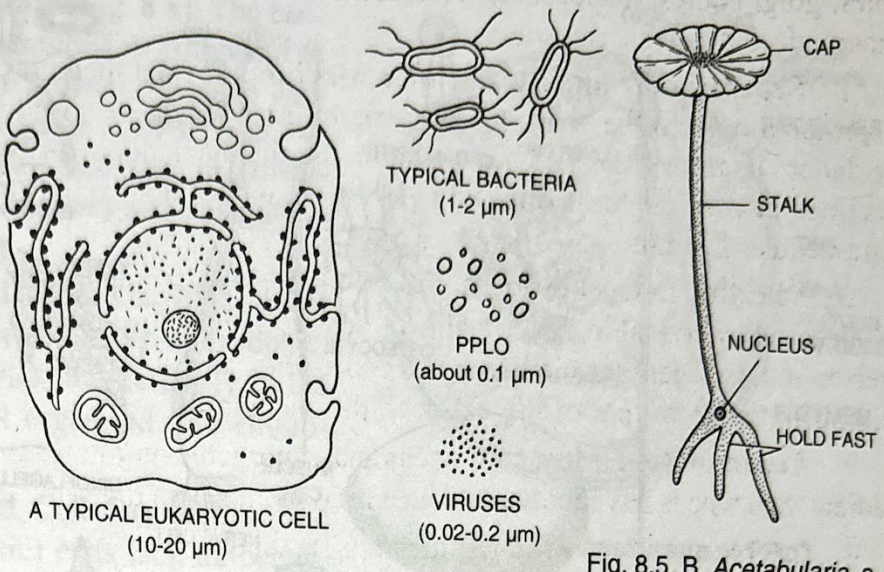

Fig. 8.5. A, Comparison of a typical eukaryotic cell with other unicellular organisms.

Fig. 8.5. B, *Acetabularia*, a single celled green alga, called umbrella plant.

In general, eggs are large sized cells because they store food for partial or complete development of the embryo. Human egg is slightly over 0.1* mm or 100 µm in diameter. It has a volume 1.4×10^6 µm^3 or 0.1 million times that of the human sperm (1.7×10^1 µm^3, table 8.1). Avian eggs are the largest. Hen egg is 60 × 45 mm with a volume of 5.0×10^{13} µm^3 while the egg of Ostrich is 170 × 150 mm with a volume of 1.1×10^{15} µm^3.

Table 8.1. Mean volumes of some cells and viruses

Cell Type	*Cell Volume (Cubic mm)*	*Cell Type*	*Cell Volume (Cubic mm)*
Ostrich Egg	1.1×10^{15}	Largest Bacterium	7.0×10^{0}
Hen Egg	5.0×10^{13}	Smallest Bacterium	2.0×10^{-2}
Human Egg	1.4×10^{6}	Mycoplasma	1.0×10^{-3}
Human sperm	1.7×10^{1}	Smallest Virus	7.0×10^{-7}

Shapes of Cells. The cells vary in their shapes. They may be disc like, polygonal, columnar, cuboid, amoeboid, thread like or irregular. The shape of cell is related to its position (flat in surface cells, polygonal in cortex) and function (*e.g.*, RBCs are biconcave to pass through capillaries and carry O_2 ; WBCs are irregular to do phagocytosis, nerve cells are long to conduct impulses, sperms have tail for motility etc. ; Fig. 8.6).

On the basis of organisation of DNA, the cells are of two types— **procaryotic** and **eucaryotic**. The organisms having procaryotic cells are called procaryotes. They are nowa-days placed in a superkingdom called **Procaryota**. Other organisms (having eucaryotic cells) are included in superkingdom **Eucaryota**. Procaryotic cells occur in bacteria, blue green algae, chlamydiae, Archaebacteria and Mycoplasma or PPLO.

* 1 centimetre or cm = 10 millimetres or mm.
1 millimetre or nm = 1000 micrometres or mm
1 micrometre or mm = 1000 nanometres or nm
1 nanometre or nm = 10 angstroms or Å

$1\ cm^3 = 10^3\ mm^3$
$1\ mm^3 = 10^3\ nm^3$

$1\ mm^3 = 10^9\ mm$
$1nm^3 = 10^3\ Å^3$

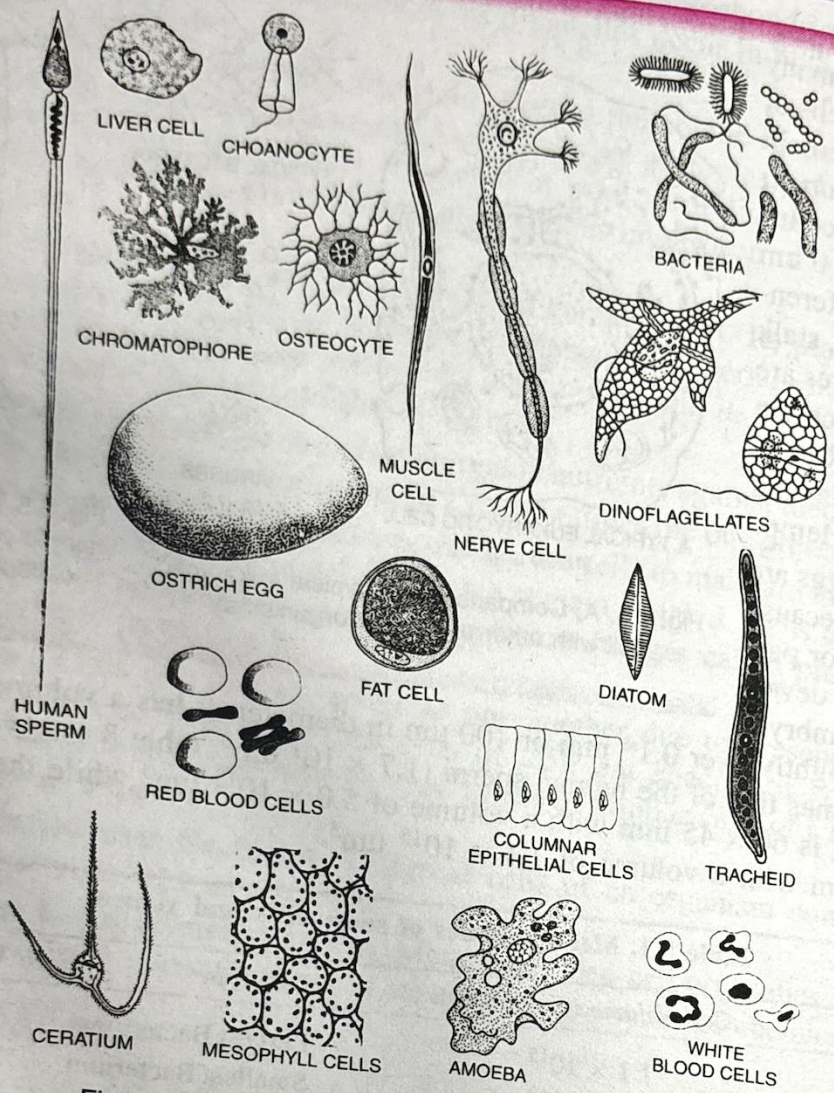

Fig. 8.6. Diagram showing different shapes of the cells.

Procaryotic Cells

Characteristics

1. **Nuclear Material.** DNA is naked and lies variously coiled in the cytoplasm. It is often called **genophore**, nuclear body or **nucleoid**. It is equivalent to a single naked chromosome and is, therefore, also called **prochromosome.** Many procaryotes also have additional small circular DNA entities called **plasmids**. Plasmids carry additional specific factors like nitrogen fixation, resistance, fertility, etc.

2. **Nuclear Components.** Nuclear envelope, nucleoplasm, nucleolus and histone covering of chromatin are absent. In eucaryotic (= eukaryotic) cells, a typical nucleus is found.

3. **Types**. Procaryota contains organisms like blue-green algae (BGA = cyanobacteria, *e.g., Nostoc*), bacteria, pleuropneumonia-like organisms or PPLO (*e.g., Mycoplasma*), archaebacteria, spirochaetes, rickettsiae and chlamydiae. PPLOs are the smallest free living organisms (Fig. 8.7).

4. **Cell Wall.** It is present in bacteria and cyanobacteira. A cell wall is absent in mycoplasma or PPLO.

5. **Flagella and Fimbriae.** Flagella are present in some bacteria only (Fig. 8.8). The bacterial flagella are single-stranded as compared to 11-stranded flagella of eucaryotes. In some bacteria, nonmotile appendages called **pili** or **fimbriae** also occur. They take part in attachment (*e.g., Neisseria gonorrhoeae*) and conjugation (*e.g., Escherichia coli*).

6. **Photosynthetic Thylakoids.** Blue - green algae and some bacteria are photo-autotrophic. Their photosynthetic thylakoids lie freely in the cytoplasm. They are not organised into chloroplasts.

7. **Membrane-lined Cell Organelles.** The procaryotic (= prokaryotic) cells lack mitochondria, endoplasmic reticulum, golgi apparatus, lysosomes, microtubules*, microfilaments* and centrioles.

8. **Vacuoles.** Typical vacuoles are doubtful. Instead complex gas vacuoles are found.

9. **Ribosomes.** Ribosomes are 70S as compared to 80S. Similar 70S ribosomes occur inside chloroplasts and mitochondria of eucaryotes.

10. **One-Envelope System**. In procaryotic cells, membrane bound cell organelles are absent so that there is a single membrane that surrounds the cell. Hence, procaryotes have a single membrane or **one-envelope system**. In eucaryotes many organelles are surrounded by their own covering membranes in addition to the cell membrane that covers the whole cell. Therefore, eucaryotes have a double membrane or **two-envelope system** of organisation.

11. **Cyclosis.** Cytoplasm does not show streaming movements or cyclosis.

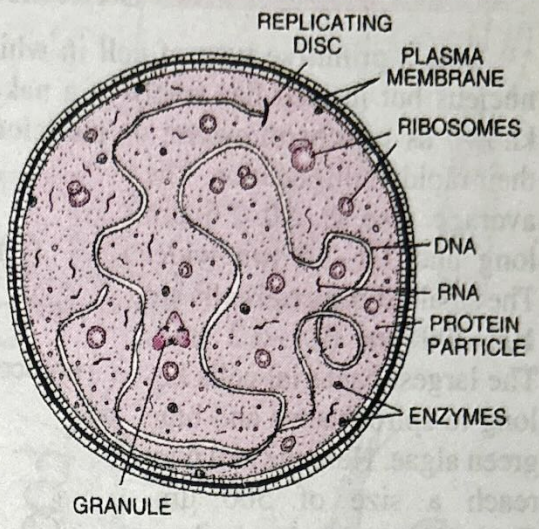

Fig. 8.7. Ultrastructure of PPLO.

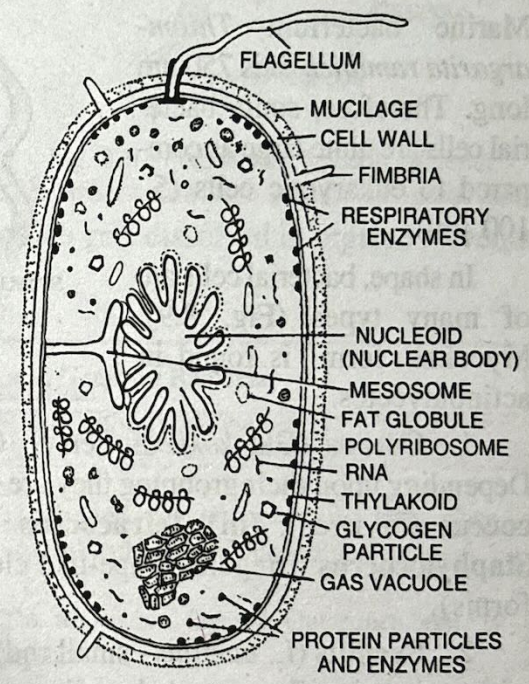

Fig. 8.8. Ultrastructure of a bacterial cell.

12. **Spindle**. Mitotic spindle is not formed during cell division.

13. **Sexual Reproduction.** It is absent. Therefore, meiosis and gamete formation are unknown. They multiply very rapidly by asexual means like binary fission, sporulation etc.

14. **DNA Content**. It is low.

15. **Transcription and Translation.** Both occur in the cytoplasm.

16. **Respiratory Enzymes**. They usually lie in contact with cell membrane.

17. **Endocytosis and Exocytosis**. They seen to be absent in procaryotes.

18. **Nitrogen Fixation**. It occurs only in some procaryotes, bacteria and cyanobacteria.

* Both of them have recently been found in some procaryotes but the same are considered to be artefacts.

Structure of a Bacterial Cell

It is a primitive type of cell in which genetic material is not organised in the form of nucleus but instead lies freely in a naked super-coiled state in the cytoplasm whence it is known as **prochromosome** or **nucleiod**. Prokaryotic (= procaryotic) cells are known for their rapid multiplication. The average size is 2.0–2.6 µm long and 1.1–1.5 µm wide. The smallest bacterial cells are 100–200 nm (0.1–0.2 µm). The largest bacterial cells belong to spirochaetes and blue green algae. Here the cell may reach a size of 500 µm. *Epulopscium fishelsoni*, a bacterium found in the intestine of Brown Surgeon Fish is 600µm long and 80 µm wide. Marine bacterium *Thiomargarita ramibiensis* is 750 µm long. Therefore, some bacterial cells are quite large as compared to eukaryotic cells (5–100 µm).

In shape, bacterial cells are of many types (Fig. 8.9). Mycelial form is found in actinomycetes.

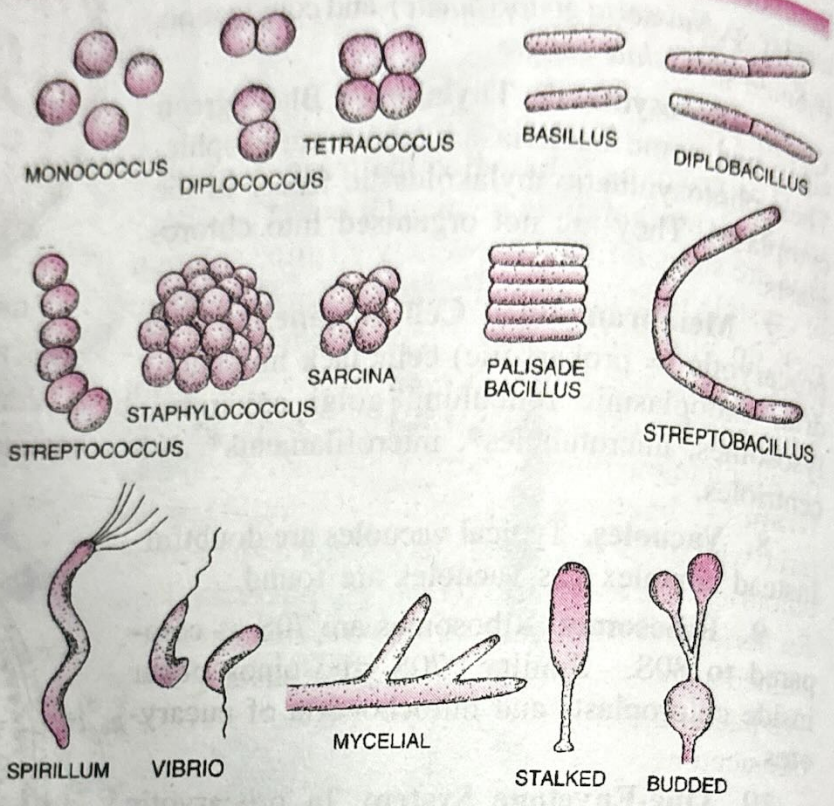

Fig. 8.9. Various forms of bacteria.

1. **Coccus** (Gk. *kokkos*– berry). Coccus bacteria are spherical or ovoid in outline. Depending upon their grouping they are called (i) **Monococcus** (occurring singly), (ii) **Diplococcus** (in twos), (iii) **Tetracoccus** (in tetrads), (iv) **Streptococcus** (in chains), (v) **Staphylococcus** (irregular grape-like clusters) and (vi) **Sarcina** (3-dimensional geometrical forms).

2. **Bacillus** (L. *bacillus*– small rod). The bacterium is straight and cylindrical like a rod with ends being flat, rounded or cigar shaped. It has three special types : (i) **Diplobacillus** (in twos), (ii) **Palisade Bacillus** (like a stack) and (iii) **Streptobacillus** (in chains).

3. **Spirillum** (L. *spira*– coil). The bacterium is coiled like a cork-screw, *e.g., Spirillum, Spirochaete*. Aggregation does not occur.

4. **Vibrio**. The body of the bacterium is like a comma, curved rod or single turn of the spiral *e.g., Vibrio cholerae*. Like spirillum bacteria, the vibrio forms live singly.

5. **Stalked**. The bacterium possesses a stalk, *e.g., Caulobacter*.

6. **Budding**. The bacterium is swollen at places, *e.g., Rhodomicrobium*.

Flagellation. Depending upon the presence or absence of flagella, bacteria are grouped into flagellate and nonflagellate types. The various forms of flagellation (Fig. 8.10) are as follows :

(a) **Atrichous.** Flagella absent.

(b) **Monotrichous**. A single flagellum occurs at or near one end of bacterium.

(c) **Amphitrichous**. A flagellum at each of the two ends.

(d) **Cephalotrichous**. A group or tuft of flagella is found only at one end.

(e) **Lophotrichous**. A tuft or group of flagella occurs at each of the two ends or poles.

(f) **Peritrichous**. A number of flagella are distributed all over the surface.

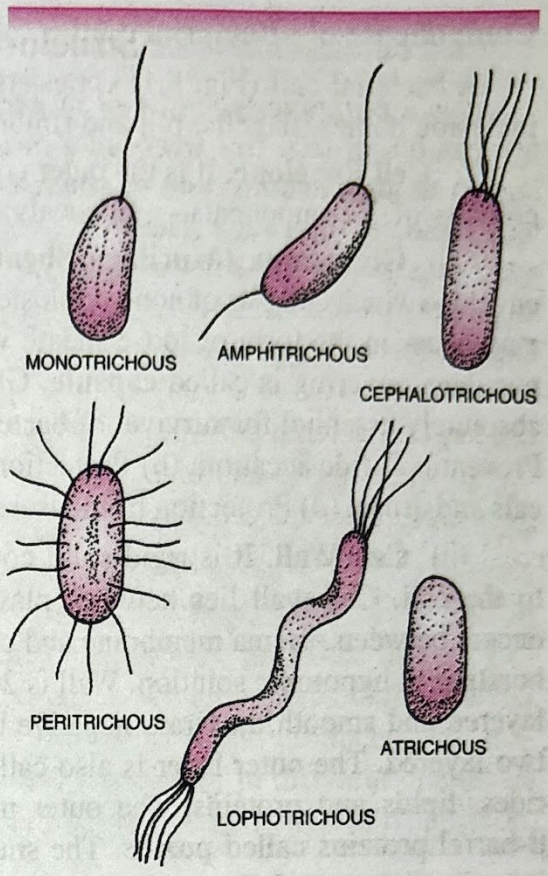

Fig. 8.10. Flagellation types in bacteria.

Gram Positive and Gram Negative Bacteria

The grouping is based on the reaction of bacteria to **Gram's stain** (Christian Gram, 1884). Bacteria are stained first with weakly alkaline solution of crystal violet or gentian violet, when all of them pick up blue colour. They are then treated with 0.5% iodine solution followed by washing with water and then absolute alcohol or acetone. Bacteria which retain blue or purple colour are known as **Gram (+) bacteria** (*e.g., Bacillus subtilis*). Bacteria which do not retain any stain and become colourless are termed as **Gram (–) bacteria** (*e.g., Escherichia coli*). (Gram–ve bacteria are commonly stained with safranin). Washing of the stain in Gram –ve bacteria is due to high lipid content of cell wall which gets dissolved in organic solvents like acetone.

Differences between Gram +*ve* and Gram-*ve* Bacteria

Gram +ve Bacteria	*Gram–ve Bacteria*
1. They remain coloured blue or purple with Gram stain even after washing with absolute alcohol or acetone.	1. The bacteria do not retain the stain when washed with absolute alcohol.
2. The wall is single layered. Outer membrane is absent.	2. The wall is two layered. Outer membrane is present.
3. The thickness of the wall is 20-80 nm.	3. It is 8-12 nm.
4. The lipid content of the wall is quite low.	4. The lipid content of the wall is 20-30%.
5. The wall is straight.	5. The wall is wavy and comes in contact with plasmalemma only at a few places.
6. Murein or mucopeptide content is 70-80%.	6. It is 10-20%.
7. Basal body of the flagellum has two rings of swellings.	7. Four rings of swellings occur in the basal body.
8. Mesosomes are more promiment.	8. Mesosomes are less prominent.
9. The bacteria are more susceptible to antibiotics.	9. They are more resistant to antibiotics.
10. Fewer pathogenic bacteria belong to Gram +ve group.	10. Most of the pathogenic bacteria are Gram –ve.
11. Porins are absent.	11. Porins or hydrophilic channels occur in outer membrane of cell wall.
12. Cell wall contains teichoic acids.	12. Teichoic acids are absent.

Components of Bacterial Cell

A bacterial cell (Fig. 8.11) consists of a cell envelope, cytoplasm, nucleiod, plasmids, inclusion bodies, flagella, pili and fimbriae.

1. **Cell Envelope**. It is the outer covering of protoplasm of bacterial cell. Cell envelope consists of 3 components— glycocalyx, cell wall and cell membrane.

(i) **Glycocalyx (Mucilage Sheath)**. It is the outermost mucilage layer of the cell envelope which consists of non-cellulosic polysaccharides with or without proteins. Glycocalyx may occur in the form of loose sheath when it is called **slime layer**. If thick and tough, the mucilage covering is called **capsule**. Glycocalyx gives sticky character to the cell. It is not absolutely essential for survival of bacteria. However, it has several secondary functions. (a) Prevention of desiccation. (b) Protection from phagocytes. (c) Protection from toxic chemicals and drugs. (d) Protection from viruses. (e) Attachment. (f) Immunogenicity (g) Virulence.

(ii) **Cell Wall**. It is rigid solid covering which provides shape and structural support to the cell. Cell wall lies between plasma membrane and glycocalyx. **Periplasmic space** occurs between plasma membrane and cell wall. Cell wall protects the bacterial cells against bursting in hypotonic solution. Wall is 20–80 nm thick in Gram positive bacteria. It is single layered and smooth. In Gram negative bacteria, wall is 8–12 nm thick, complex, wavy and two layered. The outer layer is also called **outer membrane**. It consists of lipopolysaccharides, lipids and proteins. The outer membrane has hydrophilic channels of 16-stranded β-barrel proteins called **porins**. The single layered cell wall of Gram positive bacteria and inner wall layer of Gram negative is made up of pepidoglycan, proteins, non-cellulosic carbohydrates, lipids, amino acids, etc. Peptidoglycan forms the structural network of the cell wall. It is also known as **murein** or **mucopeptide**. Peptidoglycan consists of long glycan

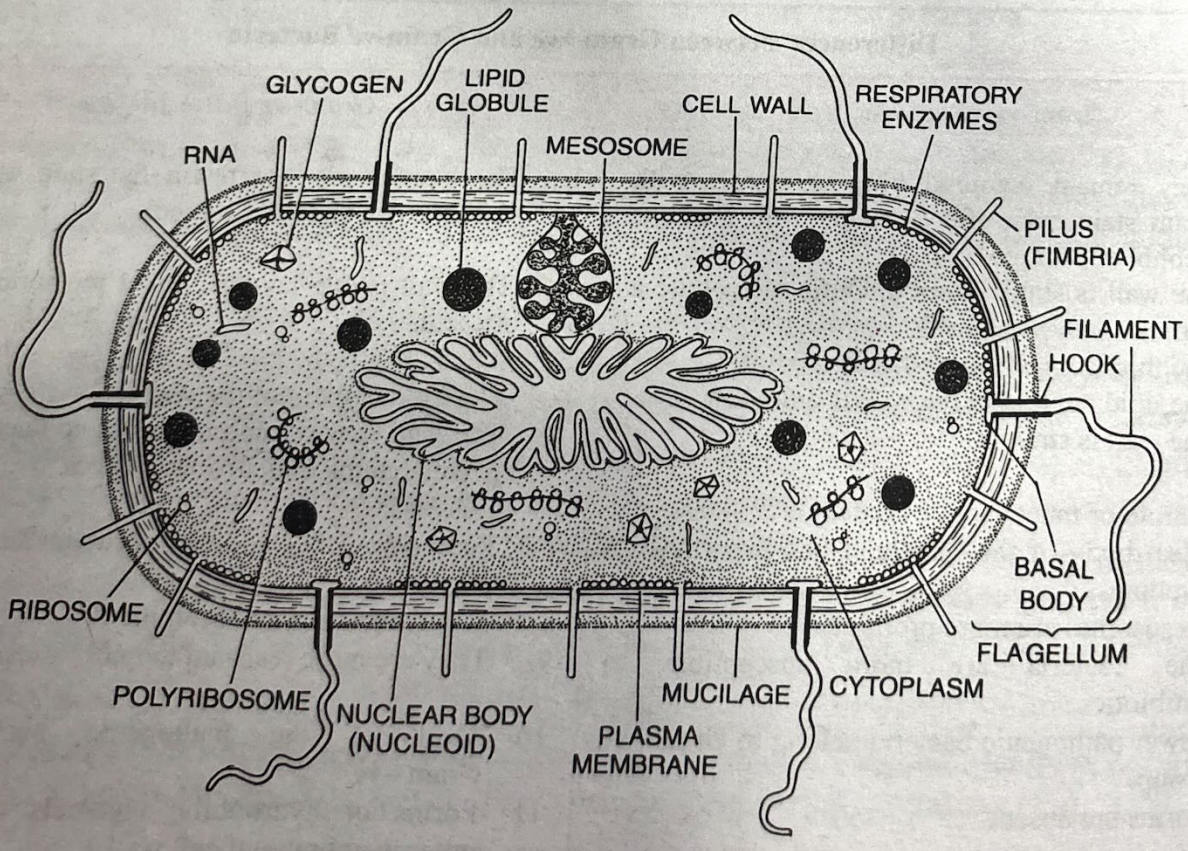

Fig. 8.11. Cell structure under electron microscope (Plasmid and volutin granules not shown).

strands formed of repeating units of N-acetyl glucosamine (NAG) and N-acetyl muranic acid (NAM). They are cross linked by small peptide chains. Certain antibiotics prevent this cross-linking and are, therefore, used for killing bacterial pathogens, *e.g.*, penicillin, cephalosporin. **Lysozyme**, the antibacterial enzyme of tears, saliva, gastric juice, etc. has the ability to hydrolyse peptidoglycan. Peptidoglycan constitutes 70–80% of wall in Gram positive bacteria. Lipid content is little. 10–20% of wall in Gram negative bacteria is formed of peptidoglycan. Lipid content is 20–30%. Amino acid present in the wall is diaminopimelic acid or lysine. In Gram positive bacteria, the wall contains teichoic acids that form receptor sites and surface antigens. In *Mycobacterium* and *Nocardia*, the wall contains long chain fatty acids called **mycolic acids**.

(iii) **Plasma Membrane**. It is selectively permeable covering of the cytoplasm that forms the innermost component of cell envelope. Bacterial plasma membrane or plasmalemma has a structure similar to that of a typical membrane. It is made of a phospholipid bilayer with proteins of various types (extrinsic, integral, transmembrane). However, typical sterols (*e.g.*, cholesterol) are absent. Instead pentacyclic sterols, called **hopanoids**, are found in some bacteria. Hopanoids stabilise the membrane. Plasma membrane holds the liquid cytoplasmic contents, separates them from surroundings, serves as selective permeability barrier allowing inward movement of nutrients and outward passage of waste products, wall materials, etc. It holds receptor molecules for detection and responding to different chemicals of the surroundings. Bacterial membrane is metabolically active as it takes part in respiration, synthesis of lipids and cell wall components.

2. **Cytoplasm**. It is crystallo-colloidal complex that forms the protoplasm excluding its nucleoid. Cytoplasm is granular due to presence of a large number of ribosomes. Membrane bound cell organelles as found in eukaryotes are absent. However, all biochemical pathways are found in prokaryotic cells. Cytoplasmic streaming is absent. Sap vacuoles are absent. Instead gas vacuoles are present. Various structures present in cytoplasm are as follows :

(i) **Mesosome** (Fitz James 1960). It is a characteristic circular to villiform specialisation of cell membrane of bacteria that develops as an ingrowth from the plasma membrane. It consists of vesicles, tubules and lamellae. Mesosme is of two types, septal and lateral. **Septal mesosome** connects nucleoid with plasma membrane. It takes part in replication of nucleoid by providing points of attachment to the replicated ones. Septal mesosome is also believed to help in septum formation. At the time of cell division, plasma membrane grows in the region where the septal mesosme is present so that most probably it provides membranes for rapid elongation. **Lateral mesosme** is not connected with nucleoid. It contains respiratory enzymes and is, therefore, often called **chondrioid**. It is beleived to be equal to mitochondrion of eukaryotes. However, respiratory enzymes are also present over the plasma membrane.

(ii) **Ribosomes.** They are small membraneless, submicroscopic ribonucleoprotein entities having a size of 20 nm × 14–15 nm. Ribosomes are of two types, fixed and free. **Fixed ribosomes** are attached to the plasma membrane. **Free ribosomes** occur free in the cytoplasmic matrix. The ribosomes are 70S in nature. (Here *S* denotes sedimentation coefficient or Svedberg number). Each ribosome has two subunits, larger 50S and smaller 30S. Ribosomes take part in protein synthesis. Free or matrix ribosomes synthesize proteins for intracellular use while fixed ribosomes synthesize proteins for transport to outside. Ribosomes generally occur in helical groups called **polyribosomes** or **polysomes**. In each polysome 4–8 ribosomes are attached to a single strand of messenger or mRNA. It is a mechanism to synthesise several copies of the same protein.

(iii) **Chromatophores**. They are internal membrane systems present in photosynthetic prokaryotes. Chromatophores develop as membrane lined sacs or **thylakoids** from plasma membrane. Thylakoid membranes contain photosynthetic pigments in cyanobacteria (blue green algae) and purple bacteria. In purple bacteria photosynthetic pigments include bacteriochlorophyll, bacterio-phaeophytin (bacterio-viridin) and carotenoids. In cyanobacteria thylakoid membranes contain chlorophyll *a* and carotenoids. Small sacs or granules containing pigments, phycobilins, are attached to these membranes. In green bacteria the chromatophores are covered by non-unit, non-lipid, protein membrane. They are sometimes called **chlorosomes**.

3. **Nucleoid**. It represents the genetic material of prokaryotes. Several alternative names have been given to nucleoid— **genophore, prochromosome, incipient nucleus** and **chromoneme**. Nucleoid consists of a single circular strand of DNA duplex which is supercoiled with the help of RNA and polyamines to form a nearly oval or spherical complex. The folding is 250-700 times. Polyamines or nucleoid proteins are different from histone proteins. DNA of prokaryotes is considered **naked** because of its non-association with histone proteins and absence of nuclear envelope around it. In *E.coli*, nucleoid has 1100 μm long DNA duplex with 4.6×10^6 base pairs. Nucleoid is embedded freely in the cytoplasm. A cell can have 2 or more nucleoids but all are replicated copies of same nucleoid. It is equivalent to a **single chromosome** of eukaryotes because nucleoid consists of a single DNA double strand. Nucleoid may be directly attached to the plasma membrane or through the mesosome.

4. **Plasmids**. They are self replicating, extra chromosomal segments of double stranded, circular, naked DNA. Plasmids provide unique phenotypic characters to bacteria. They are independent of main nucleoid. Some of them contain important genes like fertility factor, nif genes, resistance factors and colicinogenic factors. Plamsids which can get associated temporarily with nucleoid are known as **episomes**. Plasmids are used as vectors in genetic engineering.

5. **Inclusion Bodies**. They are non-living structures present in the cytoplasm. The inclusion bodies may occur freely inside the cytoplasm (*e.g.*, cyanophycean granules, volutin or phosphate granules, glycogen granules) or covered by 2-4 nm thick non-lipid, non-unit protein membrane (*e.g.*, gas vacuoles, carboxysomes, sulphur granules, PHB granules). On the basis of their nature, the inclusion bodies are of 3 types— gas vacuoles, inorganic inclusions and food reserve.

(i) **Gas Vacuoles**. They are gas storing vacuoles found in cyanobacteria, purple and green bacteria and a few other planktonic forms. A gas vacuole is without any covering of its own. It consists of a variable number of hexagonal, hollow and cylindrical **gas vesicles**. Each gas vesicle is surrounded by a single non-unit, non-lipid protein membrane having ribs or folds. The membrane is impermeable to water but is permeable to atmospheric gases. Gas vacuoles protect the bacteria from harmful radiations. They also constitute buoyancy regulation mechanism for their proper positioning in water during daytime for photosynthesis.

(ii) **Inorganic Inclusions.** Several types of inorganic granules occur in bacteria. They include volutin granules, sulphur granules, iron granules, magnetite granules, etc. Because of the ability to pick up different colours with basic dyes, they are called **metachromatic granules**. Two common types of inorganic granules are volutin granules and sulphur granules. Volutin granules are polymetaphosphates which function as storage reserve of phosphate. Sulphur granules occur in bacteria living in sulphur rich medium like the one which pick up hydrogen sulphide for obtaining reducing power in photosynthesis. Iron granules are similarly found in those bacteria which metabolise iron compounds for obtaining energy.

Aquaspirillum magnetotacticum contains **magnetosomes,** which are vesicles having magnetite. The granules help the bacteria to orientate themselves along geomagnetic lines.

(iii) **Food Reserve**. Blue green algae have **cyanophycean starch** or α–granules, β-granules or **lipid globules** and **cyanophycin** or protein granules. In bacteria, starch is replaced by glycogen. Neutral fats are absent. Instead **poly-beta-hydroxy-butyrate** or PBH granules are present. A biodegradable plastic can be prepared from PBH. Protein granules are present. Carboxysomes occur in photosynthetic forms.

6. **Flagella** (Fig. 8.12). Bacterial flagella are unistranded, equivalent to a single microtubular fibre. It is about 20 nm (0.02 μm) in diameter and 1-7μm in length. Bacterial flagellum is made up of 3 parts— **basal body**, **hook** and **filament**. Basal body is like a rod. It is inserted in the cell envelope. The basal body bears ring-like swellings in the region of plasma membrane and cell wall. There are two pairs of rings (L and P ring in cell wall and S and M rings embedded in cell membrane) in Gram negative bacteria and only a single pair of rings (S and M rings embedded in cell membrane) in Gram positive bacteria (Fig. 8.12 B). Hook is curved tubular structure which connects the filament with the basal body. It is the thickest part of flagellum. Filament part is long tubular structure which causes turbulence in the liquid medium. It is made up of protein called **flagellin.** Protein molecules are globular. They are arranged in 3–8 spiral rows (Fig. 8.12 C). It is believed (Lowy and Spencer, 1968) that bacterial flagella perform rotation type movement that brings about backward pushing of the water. It results in the bacterium moving forward.

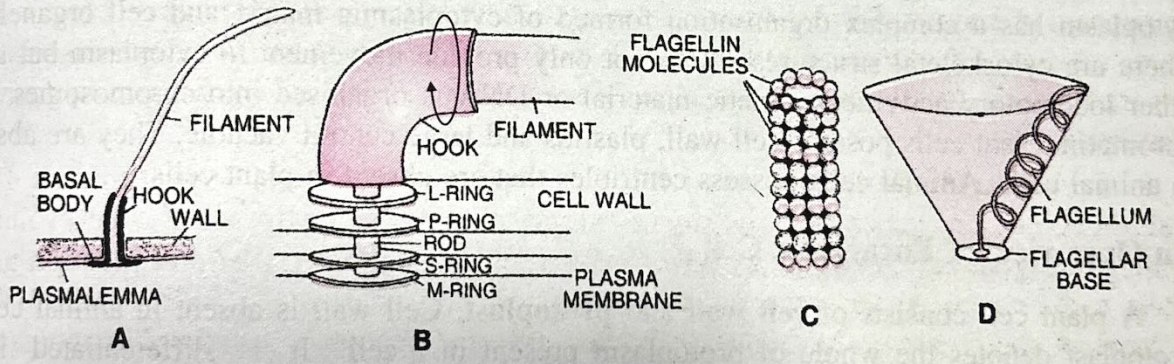

Fig. 8.12. Bacterial flagellum. A, parts of flagellum. B, Lower region of flagellum of a Gram negative bacterium. C, filament canal with flagellin molecules. D, mode of flagellar movement.

7. **Pili and Fimbriae**. The two terms have been used interchangeably for bacterial appendages which are not involved in locomotion. Actually, pili (singular-pilus) are longer, fewer and thicker tubular outgrowths which develop in response to F^+ or fertility factor in Gram negative bacteria. They are made up of protein **pilin**. A donor bacterial cell having fertility factor develops 1–4 pili. Being long (18–20 μm) they are helpful in attaching to recipient cell and forming conjugation tube.

Fimbriae are small bristle-like fibres sprouting from cell surface in large number. There are 300–400 of them per cell. Diameter is 3–10 nm while length is 0.5–1.5 μm. Fimbriae are involved in attaching bacteria to solid surfaces (*e.g.*, rock in water body) or host tissues (*e.g.*, urinary tract in *Neisseria gonorrhoeae*). Some fimbriae cause agglutination of RBC. They also help in mutual clinging of bacteria.

Pili	*Fimbriae*
1. They occur only in Gram negative bacteria.	1. Fimbriae are found in both Gram +ve and Gram –ve bacteria.
2. The number is 1-4 per cell.	2. The number is 300-400 per cell.
3. Pili are longer and broader.	3. Fimbriae are shorter and narrow.
4. They help in conjugation.	4. They take part in adhesion.
5. Formation of pili is controlled by F^+ or fertility factor.	5. Formation of fimbriae is controlled by a nucleoid gene.
6. They are tubular structures.	6. They are bristle-like solid structures.

Eucaryotic Cells

A eucaryotic cell is the one which has an organised nucleus and several membrane overed cell organelles. Except monera, the cells of all other kingdoms have eukaryotic rganisation. Cell wall is present in cells of plants, fungi and some protists. It is absent in nimal cells and some protists. Wall-less cells are generally irregular. Otherwise, internal tructure of all cells is somewaht similar. *A cell is an organised mass of protoplasm surounded by a protective and selectively permeable membrane*. Protoplasm of a cell is called **rotoplast** (Hanstein, 1880). It is made up of cytoplasm, nucleus and vacuoles. Initially, ytoplasm was thought to have simple organisation. Electron microscope has shown that ytoplasm has a complex organisation formed of cytoplasmic matrix and cell organelles. here are cytoskeletal structures which not only provide movement to cytoplasm but also her locomotory activities. Genetic material or DNA is organised into chromosomes and romatin. Plant cells possess cell wall, plastids and large central vacuole. They are absent animal cells. Animal cells possess centrioles that are absent in plant cells.

n Over view of Eucaryotic Cell

A plant cell consists of **cell wall** and **protoplast**. Cell wall is absent in animal cells. otoplast denotes the whole of protoplasm present in a cell. It is differentiated into **sma membrane** (= plasmalemma or cell membrane), **cytoplasm, nucleus** and **vacuoles**. toplasm is distinguishable into **cytoplasmic matrix** and **organelles**. Cytoplasmic matrix lso called **hyaloplasm**. It is a polyphasic colloidal system which exists in two states, sol gel. The gel form usually occurs near the plasma membrane. This region is sometimes ed **ectoplast** in contrast to sol region known as **endoplast.** Ectoplast is firmer. It is quite spicuous on the free sides of the cells. In protozoans, ectoplast is prominent on all sides. oplasmic matrix is generally in perpetual motion. The phenomenon is called **cyclosis**, plasmic or protoplasmic streaming. Cytoplasmic matrix occupies the volume of the cells. the major arena of cellular activities that keep a cell in the living state.

In the cytoplasmic matrix are embedded a large number of **cell organelles** or organised oplasmic subunits having specific functions. They are endoplasmic reticulum, plastids, chondria, ribosomes, Golgi bodies, centrioles (central apparatus, centrosome), lysos-, sphaerosomes, peroxisomes, glyoxysomes, vacuoles, microtubules, microfilaments, Some of them have membrane covering while others are without the same. Doubling brane covering occurs around plastids and mitochondria. Single membrane covering is d over endoplasmic reticulum, Golgi apparatus, lysosomes, sphaerosomes, peroxisomes,

glyoxysomes and vacuole. Organelles without a membrane covering are ribosomes, microtubules, microfilaments and centrosomes or centrioles (in animal cells). Ribosomes are found in both prokaryotes and eukaryotes. In eukaryote cells they occur in cytoplasmic matrix, over rough endoplasmic reticulum, inside plastids (found only in plants and some protists and mitochondria).

Cell inclusions include starch grains, glycogen granules, fat droplets, aleurone grains, excretory or secretory products and crystals.

Nucleus is also embedded in the cytoplasmic matrix. It is surrounded by a double membrane envelope and contains nucleoplasm, one or more nucleoli and chromatin having DNA. DNA is the genetic material.

Functions of Cell Parts

1. **Cell Wall**— Shape, rigidity and protection to cell.
2. **Plasma membrane**— Regulation of substances leaving or entering a cell.
3. **Cytoplasm.** (a) *Endoplasmic Reticulum*— Cytoskeleton, channelisation, synthesis of fats, steroids, proteins, formation of vacuoles and vesicles. (b) *Ribosomes*— Protein synthesis. (c) *Mitochondria*— Krebs cycle, amino acid synthesis, fatty acid synthesis. (d) *Chloroplasts*— Photosynthesis. (e) *Amyloplasts*— Storage of starch. (f) *Golgi Apparatus*— Storage, secretion, excretion, wall synthesis, some chemical transformations, membrane transformation, lysosome formation. (g) *Centrioles*— Formation of astral poles, flagella. (h) *Lysosomes*— Separation and storage of hydrolytic (digestive) enzymes, digestion, autophagy. (i) *Sphaerosomes*— Metabolism, storage and synthesis of fats. (j) *Glyoxysomes*— Glyoxylate cycle, conversion of fat to carbohydrates. (k) *Peroxisomes*— Photorespiration, peroxide metabolism. (l) *Microtubules*— Cytoskeleton, formation of spindle and flagella. (m) *Microfilaments*— Holding of membrane proteins, controlling cleavage and cyclosis. (n) *Vacuole*— Osmotic pressure, storage.
4. **Nucleus**— Carrier of hereditary information, control of cell metabolism, cell differentiation, synthesis of DNA and RNA, formation of ribosomes, control of reproduction.

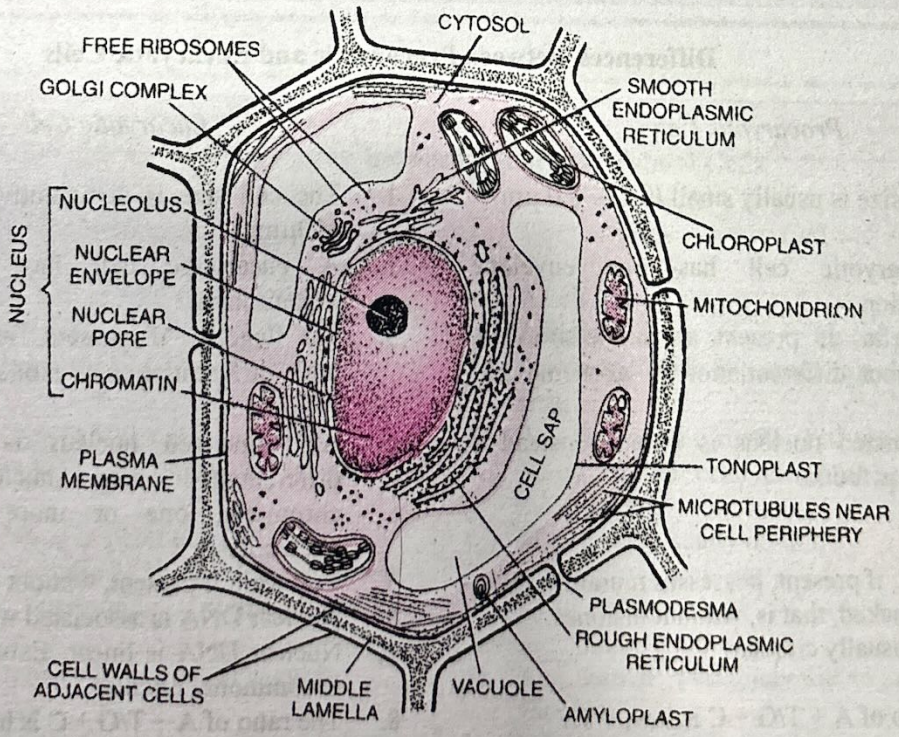

Fig. 8.13. A generalised ultra structure of an eucaryotic plant cell.

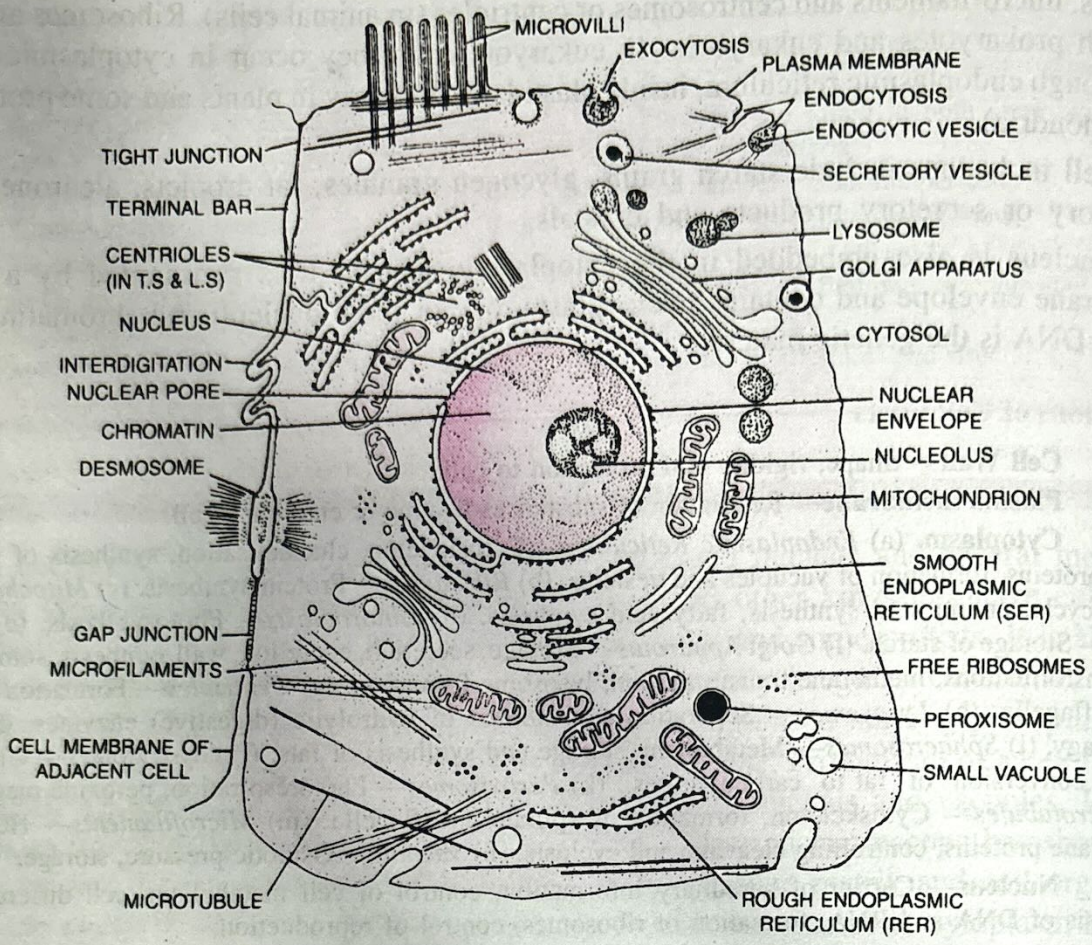

Fig. 8.14. A generalised ultrastructure of an eucaryotic animal cell.

Differences between Procaryotic and Eucaryotic Cells

Procaryotic Cell	*Eucaryotic Cell*
1. The cell size is usually small (0.1— 5.0 μm).	1. The cell size is comparatively larger (5— 100μm).
2. A procaryotic cell has one envelope organisation.	2. A eucaryotic cell has two envelope organisation.
3. The flagella, if present, are single stranded, and without differentiation of axoneme and sheath.	3. The flagella, if present, are 11-stranded, with differentiation of axoneme and sheath.
4. An organized nucleus is absent. Instead a nucleoid is found.	4. An organized nucleus is found. It is differentiated into nuclear envelope, chromatin, one or more nucleoli and nucleoplasm.
5. Cell wall, if present, possesses muramic acid.	5. Cell wall, if present, without muramic acid.
6. DNA is naked, that is, without histones.	6. Nuclear DNA is associated with histones.
7. DNA is usually circular.	7. Nuclear DNA is linear. Extra nuclear DNA is commonly circular.
8. The ratio of A + T/G + C is low, < 1.	8. The ratio of A + T/G + C is high, > 1.
9. DNA lies freely in the cytoplasm. It is not associated with any organelle.	9. Most of the cell DNA lies in the nucleus. A small quantity is also found in the plastids and mitochondria.

10. The amount of DNA does not change as there are no haploid and diploid stages.
11. Transcription and translation occur in the cytoplasm.
12. Protein synthesis occurs only in cytoplasm.
13. Respiratory enzymes are associated with plasma membrane.
14. Endocytosis and exocytosis are absent.
15. Cytoplasm does not show cyclosis.
16. Ribosomes are of 70 S type.
17. Membrane bound organelles like ER, mitochondria, Golgi apparatus, centrioles, lysosomes and other microbodies are absent.
18. True or sap vacuoles are usually absent. Instead, gas vacuoles, may be found.
19. Microtubules and microfilaments are commonly absent.
20. Thylakoids, if present, lie freely in cytoplasm.
21. Gametes are not formed, since sexual reproduction and meiosis are absent.
22. A spindle apparatus is not formed during division.
23. Nucleoid is equivalent to a single chromosome or prochromosome.

10. The amount of DNA shows a regular alternation between diploid and haploid stages.
11. Transcription occurs in the nucleus while translation takes place in the cytoplasm.
12. Protein synthesis takes place in cytoplasm, mitochondria and plastids.
13. Respiratory enzymes are present in both cytoplasm as well as mitochondria.
14. They are quite common.
15. Cytoplasm usually shows cyclosis.
16. Ribosomes are of 80S type. 70S ribosomes however, occur in plastids and mitochondria.
17. Mitochondria, ER, Golgi apparatus and microbodies including lysosomes, centrioles are present in cells of organisms in which motile stage is present in the life cycle.
18. True or sap vacuoles are commonly found.
19. Microtubules and microfilaments are important constituents of eucaryotic cells.
20. Thylakoids, if present, are grouped inside the chloroplasts.
21. Gametes are formed either directly or through meiosis, as sexual reproduction is found in the life cycle.
22. A spindle apparatus is produced during nuclear division.
23. Nucleus contains more than one chromosomes.

Differences between Plant and Animal Cells

Plant Cell	*Animal Cell*
1. A plant cell has a rigid wall on the outside.	1. A cell wall is absent.
2. It has a definite form.	2. A definite form is less common.
3. It is usually larger in size.	3. An animal cell is comparatively smaller in size.
4. It cannot change its shape.	4. An animal cell can often change its shape.
5. It cannot change its pisition or move about.	5. Many animal cells can change position or move about.
6. Plastids are found in plant cells.	6. Plastids are usually absent.
7. Plant cells exposed to sunlight possess chlorophyll containing plastids called chloroplasts.	7. Chlorophyll is absent.
8. A mature cell has a large central vacuole.	8. An animal cell may have many small vacuoles.
9. Nucleus lies on one side in the peripheral cytoplasm due to central vacuole.	9. Nucleus usually lies in the centre.
10. Nucleus is elliptical.	10. Nucleus is rounded.
11. Mitochondria are comparatively fewer.	11. Mitochondria are generally numerous.

12. Plant cells do not burst if placed in hypotonic solution due to the presence of cell wall.	12. Animal cells usually burst if placed in hypotonic solution unless and until they possess contractile vacuoles.
13. Centrioles are usually absent.	13. Centrioles are found in animal cells.
14. Spindle apparatus formed during nuclear division is anastral.	14. Spindle is amphiastral.
15. Golgi apparatus consists of a number of distinct or unconnected units called dictyosomes.	15. Golgi apparatus is either localised or consists of a well connected single complex.
16. The cell cannot take part in phagocytosis.	16. It can ingest materials through phagocytosis.
17. Lysosomes are rare. Their activity is performed by specialised vacuoles.	17. Typical lysosomes occur in animal cells.
18. Glyoxysomes may be present.	18. They are absent.
19. A plant cell produces all the materials needed by it.	19. An animal cell cannot synthesise certain amino acids, fatty acids, vitamins and coenzymes needed by it.
20. Crystals of inorganic substances occur inside the cells.	20. Crystals usually do not occur in animal cells.
21. Reserve food is generally starch and fat.	21. Reserve food is usually glycogen and fat.
22. A tissue fluid does not bathe the cells.	22. A tissue fluid having NaCl bathes cells.
23. Adjacent cells may be connected through plasmodesmata.	23. Adjacent cells are connected through a number of cell junctions.
24. Cytokinesis occurs by cell plate.	24. Cytokinesis takes place by cleavage.

The various cell components of eukaryotic cells are described below to understand their structure and functions.

I. Cell Wall

It is the outer rigid protective supportive and semitransparent covering of plant cells, fungi and some protists. Cell wall was first seen in cork cells by Hooke in 1665. Its thickness varies in different types of cells from 0.1 μm to 10 μm. Cell wall is a non-living extracellular secretion or matrix of the cell which is closely appressed to it. It is, however, metabolically active and is capable of growth. Cell wall performs a number of functions :

(i) Protects the protoplasm against mechanical injury. (ii) Protects the cell from attack of pathogens. (iii) Provides rigidity and shape to the cell. (iv) Counteracts osmotic pressure. (v) Gives strength to the land plants to withstand gravitational forces. (vi) By its growth the wall helps in cell expansion. (vii) Pits present in the wall help produce a protoplasmic continuum or **symplast** amongst cells. (viii) Walls prevent bursting of plant cells by inhibiting excessive endosmosis. (ix) Wall has some enzymatic activity connected with metabolism. (x) In many cases, wall takes part in offence and defence. (xi) Cutin and suberin of the cell wall reduce the loss of water through transpiration. (xii) Walls of sieve tubes, tracheids and vessels are specialised for long distance transport. (xiii) Some seeds store food in the form of hemicellulose in cell wall.

Chemical Composition of Cell Wall

1. **Matrix**. Water— 60%. Hemicellulose— 5–15%. Pectic Substances— 2–8%. Lipids— 0.5–3.0%. Proteins— 1–2%

2. **Microfibrils**. Cellulose/fungus cellulose— 10–15%.

3. **Other Ingredients**. Lignin, cutin, suberin, silica (silicon dioxide), minerals (*e.g.*, iron, calcium, carbonate), waxes, tannins, resins, gum— variable.

Structure of Cell Wall

A cell wall can have upto three parts— middle lamella, primary wall and secondary wall.

Middle Lamella. It is a thin, amorphous and cementing layer between two adjacent cells. Middle lamella is the first layer which is deposited at the time of cytokinesis (Fig. 8.15). It is just like brick work of the common wall between two adjacent rooms. Middle lamella is absent on the outer side of surface cells. It is made up of calcium and magnesium pectates. The softening of ripe fruits is caused by partial solubilisation of pectic compounds to produce jelly-like consistency.

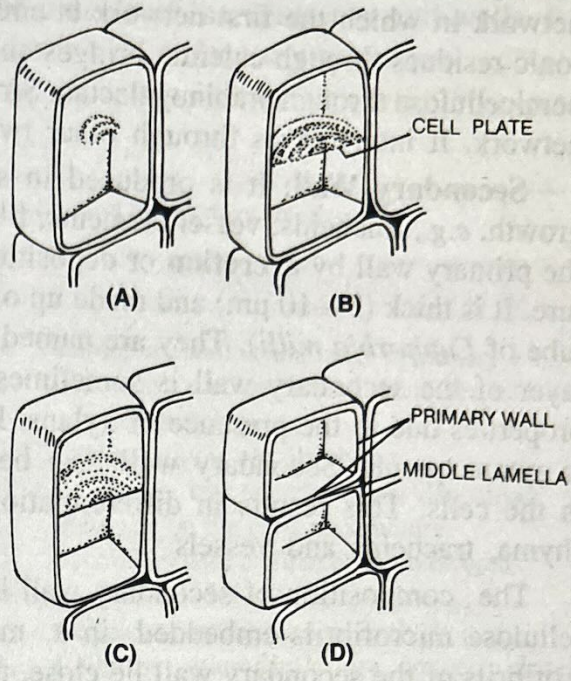

Fig. 8.15. Development of new wall at the time of cytokinesis.

Primary Wall (Fig. 8.16). It is the first formed wall of the cell which is produced inner to the middle lamella. The primary wall is commonly thin (0.1–3.0 μm) and capable of extension. It grows by intussusception or addition of materials within the existing wall. Some cells possess only primary wall, *e.g.*, leaf cells, fruit cells, cells of cortex and pith.

Primary wall consists of a number of **microfibrils** embedded in the amorphous gel-like **matrix** or ground substance. In the majority of plants, the microfibrils are formed of cellulose. They are synthesised at plasma membrane by particle rossettes (terminal complexes) having cellulase synthetase enzyme (Brown *et al*, 1996). The wall is made of a polymer of β, 1–4 acetyl glucosamine or fungus cellulose in many fungi. Fungus cellulose is similar to **chitin** present in the exoskeleton of insects. Microfibrils are oriented variously according to the shape and thickening of the wall. Usually they are arranged in a loose network due to incomplete cross-linking.

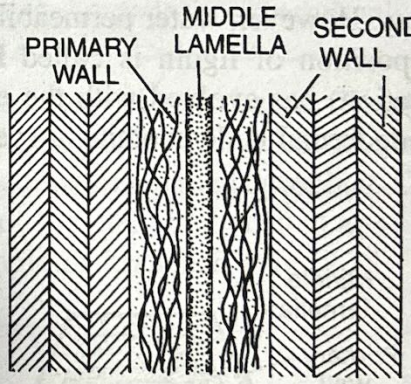

Fig. 8.16. Arrangement of microfibrils in the common wall between two adjacent cells as seen in L.S.

The matrix of the wall consists of galactans, mannans and minerals like calcium carbonate in lower cryptogams like algae. In others it contains water, pectin, hemicellulose and glycoproteins. **Pectin** is the filler substance of the matrix. It is a mixture of polymerised and methylated galacturans, galacturonic acid and neutral sugars. Proteins are **structural** and **enzymatic**. A hydroxy protine rich glycoprotein previously called **extensin** connects pectin with hemicellulose. A water soluble protein called **arabinoglactan protein** (AGP) helps in adhesion and signalling during differentiation. Protein **expansin** (Mc Queen-Mason *et al*, 1992) is involved in loosening and expansion of cell wall through incorporation of more cellulose. **Hemicellulose** is a mixture of polymerised xylans, mannans, glucomannans, galactans, xyloglucans and arabinoglactans. It binds microfibrils with matrix.

Microfibrils, pectic polysaccharides and structural proteins of the cell wall form three independent **networks**. Microfibrils form the first continuous lattice or network by forming

hydrogen bonds with xyloglucan end of hemicellulose. Pectic polysaccharides form a second network in which the first network is embedded. It is formed by cross-linking of galacturonic residues through calcium bridges and ionic interactions. The network is connected to hemicellulose through arabinogalactan. Structural proteins or glycoproteins produce the third network. It interweaves through other two networks like warp and weft structure.

Secondary Wall. It is produced in some mature cells when the latter have stopped growth, *e.g.*, tracheids, vessel elements, fibres, collenchyma. Secondary wall is laid inner to the primary wall by **accretion** or deposition of materials over the surface of existing structure. It is thick (3—10 μm) and made up of at least three layers, sometimes more (*e.g.*, latex tube of *Euphorbia milli*). They are named as S_1, S_2, S_3, S_x, etc. (Fig. 8.17). The innermost layer of the secondary wall is sometimes distinct both chemically as well as in staining properties due to the presence of xylans. It is then called **tertiary wall**, *e.g.*, tension wood in gymnosperms. Secondary wall may be absent, irregularly deposited or formed uniformly in the cells. This results in differentiation of cells— parenchyma, collenchyma, sclerenchyma, tracheids and vessels.

The composition of secondary wall is basically similar to the primary wall in having cellulose microfibrils embedded in a matrix of pectin and hemicellulose. Cellulose microfibrils of the secondary wall lie close, parallel and at an angle to the longitudinal axis of the cell. Their orientation is different in the different layers of the secondary wall (Fig. 8.17). A number of different materials may be deposited in the wall. The important ones are : (a) **Lignin**. It is phenol containing polymer which formed by polymerisation and dehydrogenation of aldehydes and alcohols like coniferyl and coumaryl. Lignin forms complexes with cellulose microfibrils. It reduces the water content of the wall matrix and increases its hardness. However, water permeability is not affected. The strengthening of the cell wall by the deposition of lignin is called **lignification***. The characteristic of lignification (and cutinisation) has evolved with the evolution of land plants. (b) **Suberin**. The wall of cork and endodermal cells contains a special fatty substance called suberin. Suberin makes the

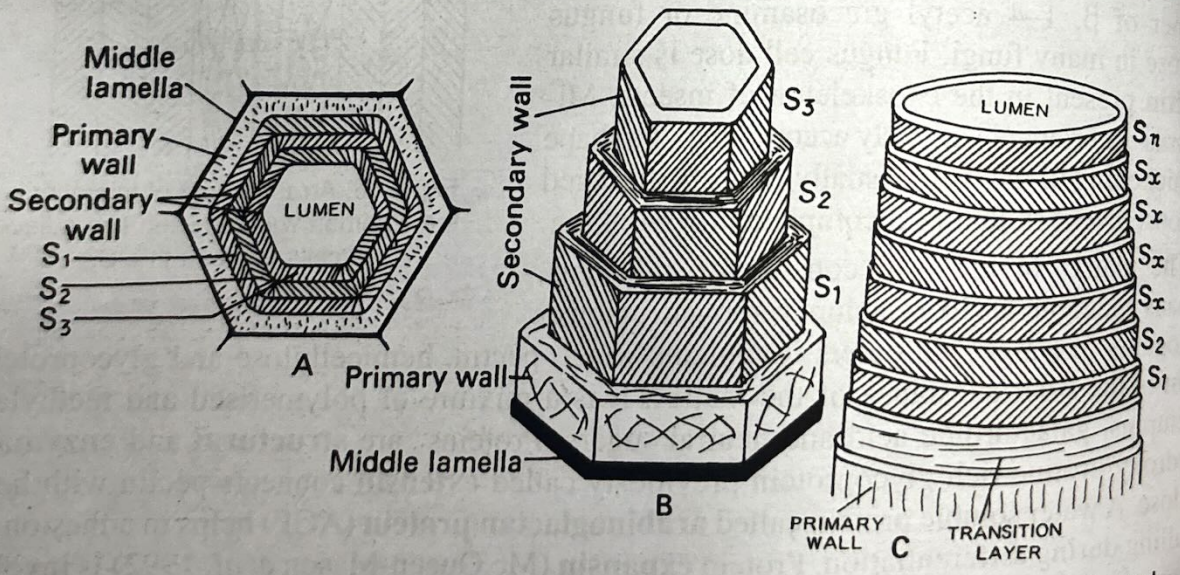

Fig. 8.17. Parts and layers of cell wall. A, a cell in T.S. showing parts of cell wall. B, typical wood fibre cut at various levels to show parts and layers of the wall. C, latex tube of *Euphorbia milli* (= *E. splendens*) cut at various levels to show parts.

*Lignin can also occur in primary wall.

walls impermeable. (c) **Cutin**. The epidermal cells possess another fatty substance called **cutin**. Cutin is also laid as a distinct layer on the outside of the epidermal cell walls. It is known as cuticle. Cutin reduces the rate of epidermal or surface transpiration.

Other substances which can be deposited in the cell wall are silica (*e.g.*, grasses), minerals, waxes, tannins, resins, gums, etc.

Differences Between Primary and Secondary Walls

Primary Wall	*Secondary Wall*
1. Primary wall is laid inner to middle lamella.	1. Secondary wall is laid inner to primary wall.
2. It is formed in young growing cell.	2. Secondary wall is formed when the cell has stopped growing.
3. It is capable of extension.	3. Extensibility is usually absent
4. The wall grows by intussusception or addition of materials inside.	4. It grows by accretion or deposition of materials on the existing structure.
5. It is single layered.	5. Secondary wall is three or more layered.
6. Hydration is 60 %.	6. Hydration is 30—40 %.
7. Cellulose content is comparatively low.	7. Cellulose content is comparatively high.
8. Cellulose microfibrils are shorter, wavy and loosely arranged.	8. Cellulose microfibrils are longer, closely aranged, straight and parallel.
9. Protein content is high, upto 5%.	9. Protein content is low, 1% or less.
10. Hemicellulose content is high, upto 50%.	10. Hemicellulose content is 25% of the total.
11. Lipid content is 5-10%.	11. Lipid is absent or negligible.
12. Additional chemicals like lignin are absent.	12. Lignin, suberin, etc. are present.
13. Primary wall is thin (0.1-3 μm).	13. Secondary wall is quite thick (3-19 μm).
14. Pits are usually absent in a primary wall.	14. Pits often occur in the secondary wall.

Plasmodesmata. Plasmodesmata (Fig. 8.18; singular– plasmodesma; Tangl, 1879; Strasburger, 1901) are cytoplasmic bridges between adjacent plant cells which develop in the minute pores of their walls. They form a protoplasmic continuum called **symplast**. Cell wall and intercellular spaces form a non-living component of the plant body called **apoplasm.** A plasmoderma is 40–50 nm in diameter. It may be simple or branched (Fig. 8.18).

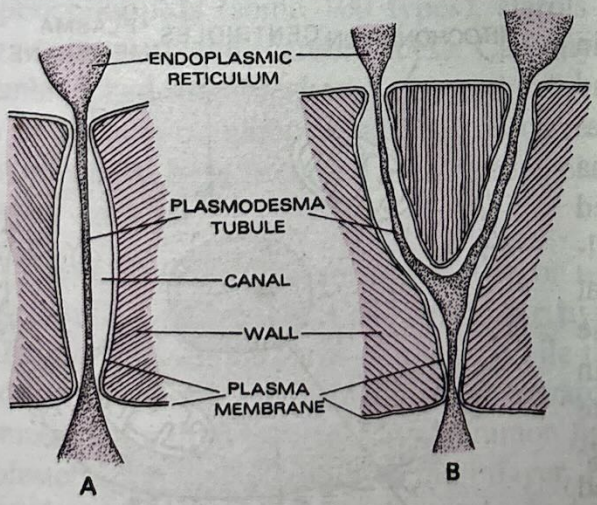

Fig. 8.18. Structure of plasmodesmata. A, simple. B, branched (as between sieve tube cells and companion cells).

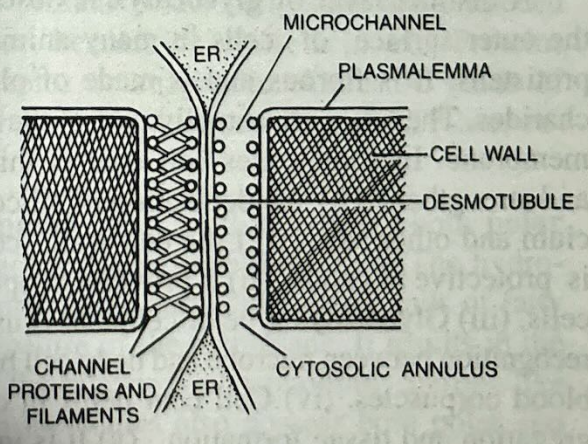

Fig. 8.19. Components of plasmodesmata.

Plasmodesma is lined by plasma membrane. It encloses tubular extension of endoplasmic reticulum called **desmotubule** (Fig. 8.19). The space between desmotubule and plasma membrane contains 8-10 microchannels (Ding *et al*, 1992). Plasmodesmata form channels for controlled passage of small sized particles between adjacent cells as well as transfer of some specific signals.

Pits. Pits are unthickened areas in the secondary walls of plant cells. They, therefore, appear as depressions. Pits generally occur in pairs on the wall of two adjacent cells. A pit has a cavity or **pit chamber** and a **pit membrane**. The pit membrane consists of primary wall and middle lamella.

Pits are of two types, **simple** and **bordered** (Fig. 8.20). Simple pit has uniform width of the pit chamber. In bordered pit, the pit chamber is flask-shaped because the secondary wall overarches its mouth.

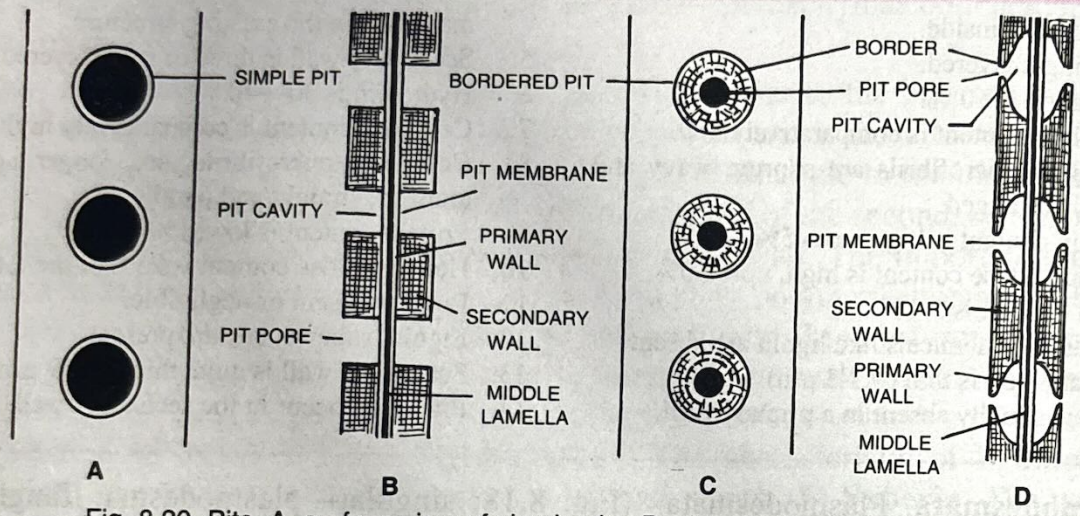

Fig. 8.20. Pits. A, surface view of simple pits. B, simple pit pairs in section. C, surface view of bordered pits. D, bordered pit pairs in section.

Pit membrane is permeable. It may have minute submicroscopic pores. Therefore, pits help in rapid translocation between two adjacent cells.

Cell Coat (Fig. 8.21)

A distinct layer of **glycocalyx** is observed in the outer surface of cells in many animals and protistans. It is fibrous and is made of oligosaccharides. The latter are actually part of the plasma membrane. In some cases cell coat is thickened and strengthened by the deposition of silicon, calcium and other salts. (i) Like cell wall, cell coat is protective in nature. (ii) It provides shape to the cells. (iii) Glycocalyx type of cell coat is useful in recognition between microbe and body cell by white blood corpuscles. (iv) Cell coat helps in cell aggregation and tissue formation. (v) It is involved in histocompatibility. (vi) Blood grouping is based on specific antigens present in the cell coat of erythrocytes.

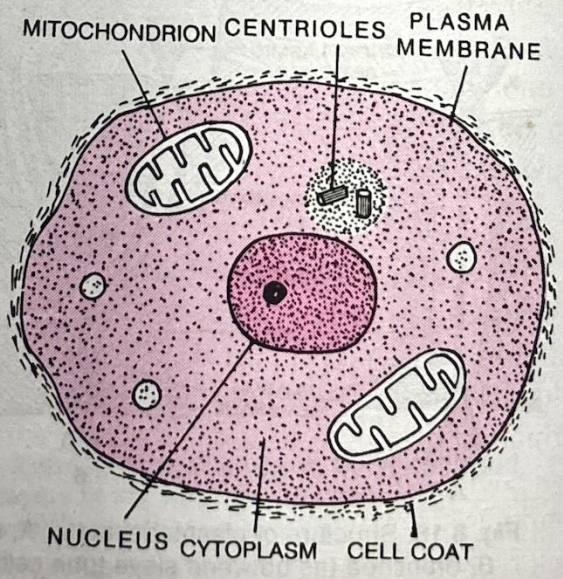

Fig. 8.21. Cell Coat.

II. Cell Membrane

The term was originally used by Nageli and Cramer (1855) for the membranous covering of the protoplast. The same was named plasmalemma by Plowe (1931). Plasmalemma or plasma membrane was discovered by Schwann (1838). Membranes also occur inside the cytoplasm of eucaryotic cells as covering of several cell organelles like nucleus, mitochondria, plastids, lysosomes, Golgi bodies, peroxisomes, etc. They line endoplasmic reticulum, cover thylakoids in plastids or form cristae inside mitochondria. Vacuoles are separated from cytoplasm by a membrane called **tonoplast**.

All membranes, whether external or internal are now called cell membranes or **biomembranes**. They are quasifluid, elastic, pliable and film-like thin partitions over and inside cytoplasm. Average thickness is 75 Å (50–100 Å). Biomembranes are **selectively permeable** for solutes but semipermeable for water. They are dynamic in nature. Any injured part of the membrane is repaired within no time.

Appearance

Biomembranes are not visible under the light microscope because their thickness is below the resolving power of the microscope. Under electron microscope biomembranes appear to be **trilaminar** or **tripartite**. There is an electron dense or dark layer on either side of middle electron transparent layer (Fig. 8.22). Freeze etching technique has shown that a membrane possesses particles of different sizes.

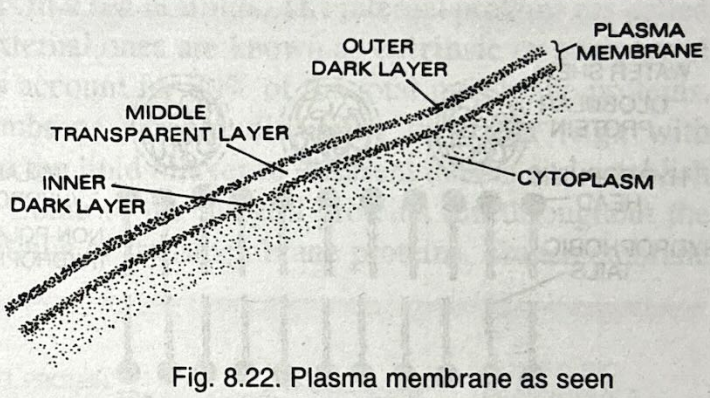

Fig. 8.22. Plasma membrane as seen under electron microscope.

Composition

Chemically a biomembrane consists of **lipids** (20–79%), **proteins** (20–70%), carbohydrates (1-5%) and water (20%). The ratio of protein and lipid varies in different membranes. Human erythrocyte membrane contains 52% protein and 40% lipid while myclinated neuron has 20% protein and 80% lipid. The important lipids of the membrane are **phosphoglycerides** or **phospholipids** (some 100 types), sterols (*e.g.,* cholesterol), glycolipids, sphingolipids (*e.g.,* sphingomyelin, cerebrosides). Carbohydrates present in the membrane are branched or unbranched oligosaccharides, *e.g.,* hexose, fucose, hexoamine, sialic acid, etc. Proteins can be fibrous or globular, structural, carrier, receptor or enzymatic. About 30 kinds of enzymes have been recorded in different biomembranes, *e.g.,* phosphatases, ATP-ase, esterases, nucleases, etc.

The lipid molecules are **amphiatic** or **amphipathic**, that is, they possess both **polar hydrophilic** (water loving) and **nonpolar hydrophobic** (water repelling) ends. The hydrophilic region is in the form of a head while the hydrophobic part contains two tails of fatty acids. Hydrophobic tails usually occur towards the centre of the membrane. It results in the formation of a lipid bilayer. Most common lipid of the bilayer is phospholipid. Sterols, like cholesterol, provide strength to the bilayer. Protein molecules also possess both polar and nonpolar side chains. Usually their polar hydrophilic linkages are towards the outer side. The nonpolar or hydrophobic linkages are either kept folded inside or used to establish connections with hydrophobic part of the lipids.

Several types of models have been put forward to explain the structure of a biomembrane. The more important are lamellar and mosaic.

Lamellar Models (= Sandwich Models, Fig. 8.23)

They are the early molecular models of biomembranes. According to these models, biomembranes are believed to have a stable layered structure.

Danielli and Davson Model (Fig. 8.23A). The first lamellar model was proposed by James Danielli and Hugh Davson in 1935 on the basis of their physiological studies. According to Danielli and Davson, a biomembrane contains four molecular layers, two of phospholipids and two of proteins. Phospholipids form a double layer. The phospholipid bilayer is covered on either side by a layer of hydrated globular or α-protein molecules. The hydrophilic polar heads of the phospholipid molecules are directed towards the proteins. The two are held together by electrostatic forces. The hydrophobic nonpolar tails of the two lipid layers are directed towards the centre where they are held together by hydrophobic bonds and van der Waals forces.

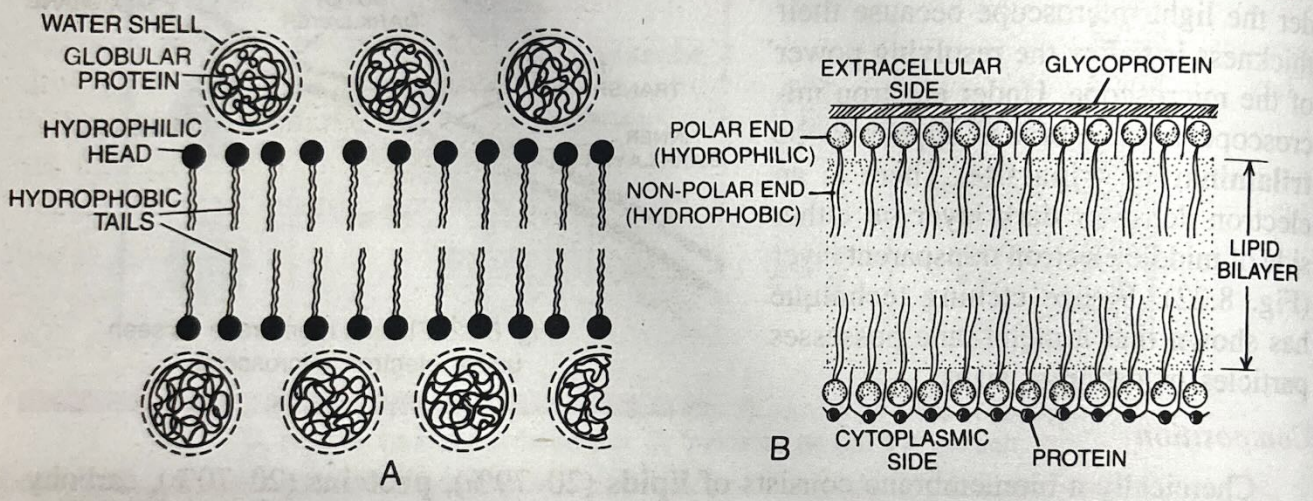

Fig. 8.23. Lamellar models of plasma membrane. A, after Danielli and Davson (1935). B, unit membrane, after Robertson (1959).

Robertson Model (Fig. 8.23B). J. David Robertson (1959) modified the model of Danielli and Davson by proposing that the lipid bilayer is covered on the two surfaces by extended or β-protein molecules. A difference in the proteins of the outer and inner layers was also proposed, *e.g.,* mucoprotein on the outer side and nonmucoid protein on the inner side. Robertson worked on the plasma membrane of red blood cells under electron microscope. He gave the concept of **unit membrane** which means that (i) All cytoplasmic membranes have a similar structure of three layers with an electron transparent phospholipid bilayer being sandwitched between two electron dense layers of proteins. (ii) All biomembranes are either made of a unit membrane or a multiple of unit membrane. The unit membrane of Robertson is also called **trilaminar membrane**. It has a thickness of about 75Å with a central lipid layer of 35Å thick and two peripheral protein layers of 20Å each. According to Robertson, if a membrane contains more than three layers, or is thicker than 75Å, it must be a multiple of unit membrane.

The two lamellar models cannot explain (i) The permeability of membranes to water (water has little affinity for phospholipid core) and electrolytes. (ii) The models are stable

and have little functional specificity and variability. (iii) The unit membrane concept is not valid since the different cytoplasmic or biomembranes differ in their form, composition and thickness. The later is 50–100Å. (iv) Protein lipid ratio does not favour lamellar models. (v) They can not explain active transport.

Mosaic Model

Fluid-Mosaic Model (Fig. 8.24). It is the most recent model of a biomembrane proposed by Singer and Nicolson in 1972. According to this model, the membrane does not have a uniform disposition of lipids and proteins but is instead a mosaic of the two. Further, the membrane is not solid but is quasifluid. The quasifluid nature of the biomembranes is shown by their properties of quick repair, dynamic nature, ability to fuse, expand and contract, grow during cell growth and cell division, secretion, endocytosis and formation of intercellular junctions.

Fluid-mosaic model postulates that the lipid molecules are present in a viscous bilayer as in lamellar model. Protein molecules occur at places both inside and on the outer side of lipid bilayer (Fig. 8.24)— **protein icebergs in a sea of lipids**. The internal proteins are called **intrinsic** or **integral** proteins while the external ones are known as **extrinsic** or **peripheral** proteins. The integral or intrinsic proteins account for 70% of the total membrane proteins. They cannot be extracted from the membrane without disrupting the latter (*e.g.*, with detergents). The integral proteins pass into the lipid bilayer to different depths and establish hydrophobic bonds with lipid molecules. Some of the integral proteins run throughout the lipid bilayer. They are called **tunnel proteins** or transmembrane proteins. Transmembrane

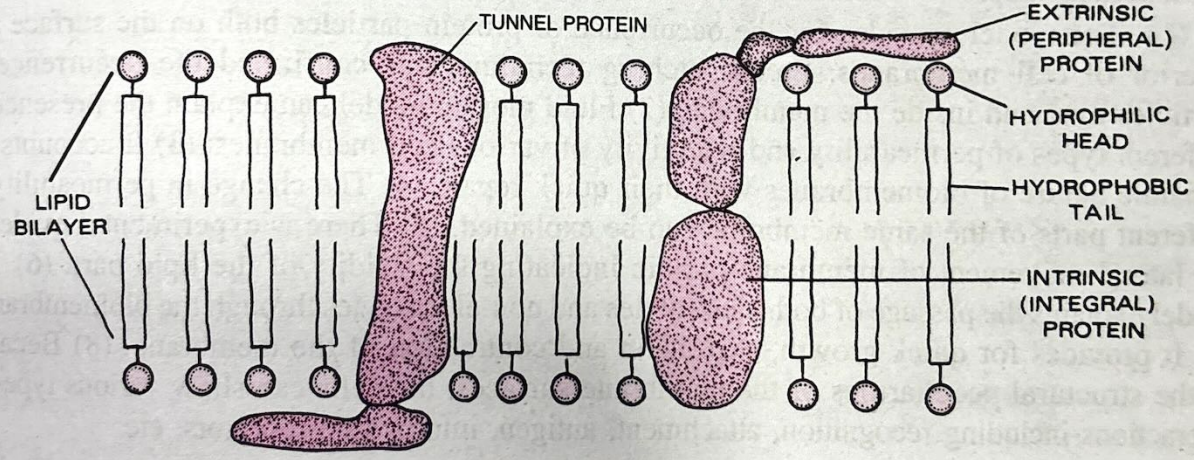

Fig. 8.24. Fluid-mosaic model of biomembrane (after Singer and Nicolson, 1972).

proteins may extend beyond the two surfaces as a single helix (*e.g.*, glycophorins). The tunnel proteins individually or in a group form channels for the passage of water and water soluble substances. The channels, however, possess selective properties for passage of different ions and other polar substances. The proteins are held in their position by both polar (to hydrophilic heads of lipids) and nonpolar (to hydrophobic tails of lipids) side chains. The **extrinsic** or **peripheral** proteins are located superficially on the two surfaces of the membrane, more so on the cytosolic face than on the external face (*e.g.*, **spectrin**). The extrinsic proteins are attached covalently to phospholipid head or noncovalently to transmembrane proteins. They can be separated with mild treatment. The proteins provide the structural and functional specificity to the membranes. Further, since the lipid bilayer is quasifluid, the membrane

proteins may **shift laterally** and thence provide flexibility and dynamism to the membrane. Many membrane proteins function as **enzymes**. Some of them behave as **permeases** for allowing facilitated diffusion. A few proteins act as **carriers** because they actively transport different substances across the membrane. Depending upon their role in active transport, carrier can be **uniporters, symporters** and **antiporters**. Certain other proteins function as **receptors** for hormones, recognition centres and antigens. Some lipids and extrinsic proteins present on the outer side possess small carbohyrate molecules to form **glycolipids** and **glycoproteins** (Fig. 8.25). They constitute **glycocalyx** or cell coat. Conjugated oligosaccharides function as recognition centres, sites of attachment, antigens, etc. Oligosaccharides also provide negative charge to the outer surface. Some workers propose the attachment of microfilaments to the membrane for stabilising the protein particles against lateral movement (Heslop-Harrison and Linskens, 1984).

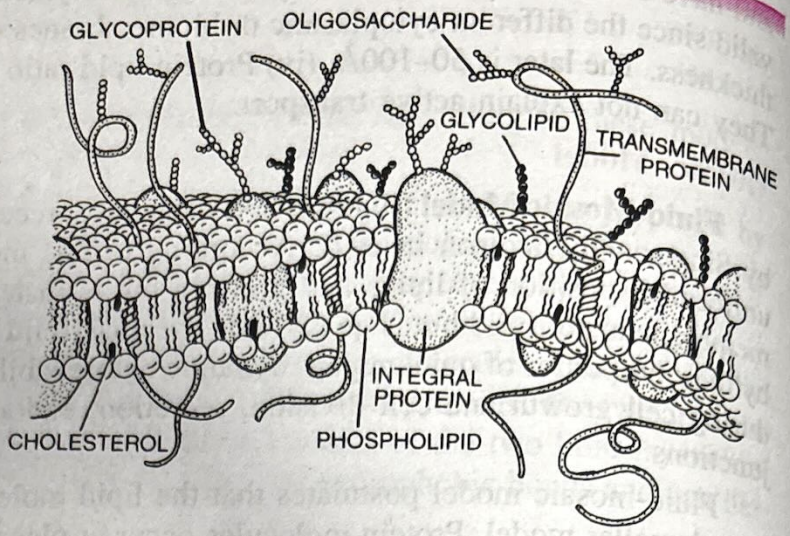

Fig. 8.25. Fluid-mosaic model of a membrane having glycocalyx or carbohydrates attached to outer proteins and lipids.

Evidences in support of Fluid Mosaic Model

(1) The model provides for the occurrence of protein particles both on the surface and interior of cell membranes. Freeze etching technique has confirmed the occurrence of particles over and inside the membrane. (2) Fluid mosaic model can explain the presence of different types of permeability and retentivity of various cell membranes. (3) It accounts for dynamic nature of biomembranes with their quick repair. (4) The change in permeability in different parts of the same membrane can be explained. (5) There is experimental evidence for lateral movement of membrane protein indicating the fluidity of the lipid part. (6) The model explains the passage of both electrolytes and non-electrolytes through the biomembranes. (7) It provides for quick growth, expansion and contraction of the membrane. (8) Because of the structural peculiarities of the membrane surfaces, the cells can show various types of interactions including recognition, attachment, antigen, information receptors, etc.

Asymmetry of Biomembranes. The two surfaces of the biomembranes are not similar, *i.e.,* the membranes are asymmetric. (i) Lipids present in the outer and inner side of the bilayer are commonly different, *e.g.,* lecithin on the outer side and cephalin on the inner side of erythrocyte membrane. (ii) The amount and types of extrinsic proteins are different on the two sides. They are more abundant on the inner surface than on the outer surface. (iii) Oligosaccharides are attached to external surface of lipids and proteins of a biomembrane. They are absent on the inner side.

Modifications of Cell Membrane (Fig. 8.26)

1. **Microvilli** (Fig. 8.26–8.27). They are finger like evaginations of 0.6–0.8 μm length and 0.1 μm diameter which are found on the free surface of cells engaged in absorption, *e.g.,* intestinal cells, hepatic cells, mesothelial cells, uriniferous tubules. The surface having microvilli is called **striated border** or **brush border**. The number of microvilli is very large

in intestinal epithelium, some 3000 per cell and 200 million per mm^2 of the surface.

Microvilli increase the surface area several times. They are supported by a web of microfilaments, actin alongwith myosin, tropomyosin, spectrin, etc. The narrow spaces in between microvilli take part in pinocytosis (Fig. 8.27).

2. **Mesosomes**. They are plasmalemma infoldings found in bacteria. One type of mesosome is attached internally to the nucleoid. It is required for nucleoid replication and cell division.

3. **Lomasomes**. They are plasmalemma foldings in fungal cells below the wall. Their exact function is not known.

4. **Endocytic Vesicles**. They are infolds that take fluid and solid pieces to the inside of cytoplasm as vesicles (pinosomes and phagosomes).

5. **Sheaths**. Plasma membrane grows over cilia and flagella to form their outer sheaths.

6. **Junctional Complexes**. They are contacts between adjacent cells which in case of animal cells are separated by spaces of 150–200 Å filled with tissue fluid. The important ones are (Fig. 8.26).

(i) **Interdigitations** (Fig. 8.26). There is interlocking of finger-like membrane outgrowths between two adjacent cells. Interdigitations increase the area of the contact between two cells for exchange of materials.

(ii) **Intercellular Bridges**. Projections from adjacent cells make contact for rapid conduction of stimuli (Fig. 8.28).

(iii) **Tight Junctions** (Zonulae Occludentes, singular—Zonula Occludens, Fig. 8.29). Here plasma membranes of two adjacent cells are fused at a series of points with a network of ridges or sealing strands. Tight junctions occur in epithelia with high electrical resistance and where filtration is to occur through the cells, *e.g.*, capillaries, brain cells, collecting tubules of kidneys.

(iv) **Gap Junctions** (Fig. 8.30). The adjacent cells have protoplasmic connections through special protein cylinders called connexons. Each connexon is made of six identical protein subunits around a hydrophilic

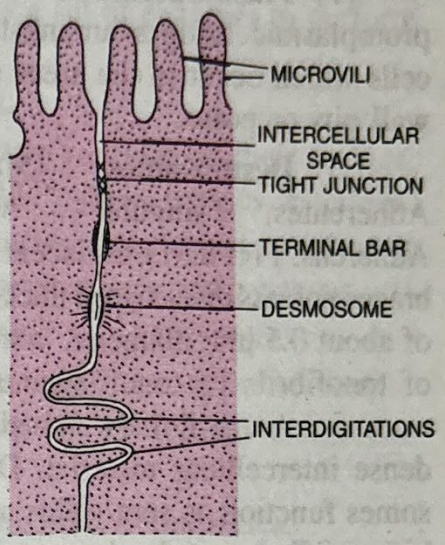

Fig. 8.26. Various modifications of cell membrane.

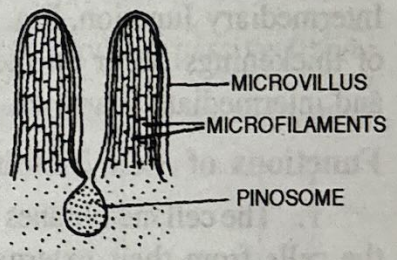

Fig. 8.27. Two microvilli and a pinosome developing in between.

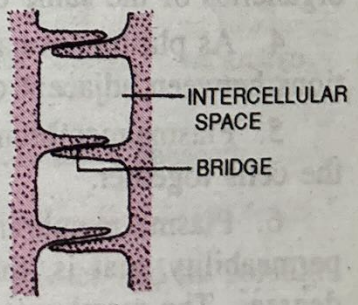

Fig. 8.28. Intercellular Bridges.

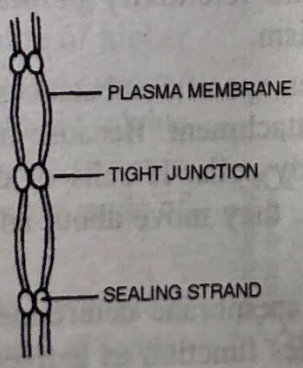

Fig. 8.29. Tight junctions between two plasma membranes.

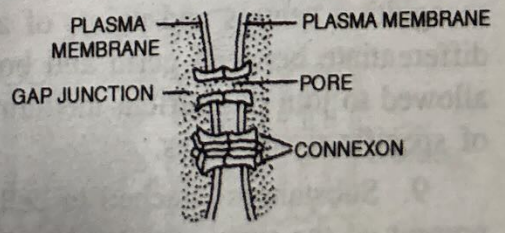

Fig. 8.30. Gap junctions between two cells.

(v) **Plasmodesmata**. They are protoplasmic bridges amongst plant cells which occur in the areas of cell wall pits or pores.

(vi) **Desmosomes** (Maculae Adherentes, singular– Macula Adherens, Fig. 8.31). Adjacent membranes possess disc-shaped thickenings of about 0.5 μm diameter, a number of tonofibrils (= tonofilaments) and trans-membrane linkers embedded in dense intercellular material. Desmosomes function as spot welds and are hence called spot desmosomes. They occur in epithelia subjected to disruption.

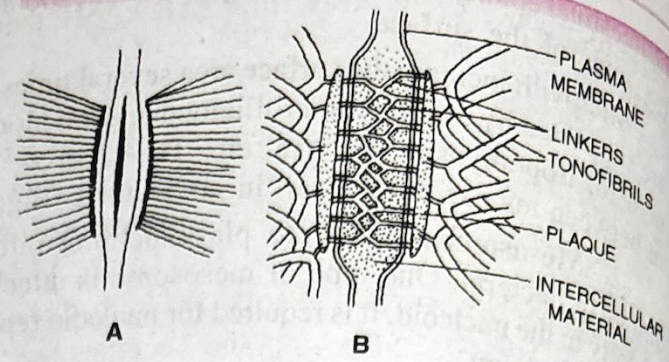

Fig. 8.31. Structure of desmosome. A, in section. B, detailed reconstruction.

(vii) **Hemidesmosomes.** The thickenings are present on one side, like the basal surface of epithelial cells. The intercellular thickening is often replaced by collagen fibrils.

(viii) **Terminal Bars** (Belt Desmosomes, Zonulae Adherentes, Singular– Zonula Adherens, Intermediary Junction, Fig. 8.26). Terminal bars are desmosomes without tonofibrils. Bands of thickenings occur on the inner surface of membrane. The bands contain microfilamens and intermediate filaments.

Functions of Cell Membranes

1. The cell membranes cause **compartmentalisation**. As plasma membranes they separate the cells from their external environment. As organelle coverings, they allow the cell organelles to maintain their identity, internal environment and functional individuality.

2. Plasma membrane protects the cell from injury.

3. The membranes allow the flow of materials and information between different organelles of the same cell as well as between one cell and another.

4. As plasmodesmata and gap junctions, the biomembranes provide organic connections between adjacent cells.

5. Plasma membranes of the adjacent cells form various types of junctions for keeping the cells together.

6. Plasma membranes as well as other membranes of the organelles have selective permeability, that is, they allow only selected substances to pass inwardly to selected degrees. The membranes are impermeable to others.

7. Differential permeability and retentivity of plasma membrane as well as other biomembranes control cell metabolism.

8. Plasma membrane possesses specific substances at its surface which function as recognition centres and points of attachment. Because of this, white blood corpuscles can differentiate between germ and body cells. If cells of different tissues get mixed up and allowed to join on nutrient medium, they move about and regroup to form distinct clusters of specific tissue types.

9. Substances attached to cell membrane determine antigen specificity. Glycophorins present on the surface of erythrocytes function as antigen determinants. Histocompatibility antigens signify whether a foreign cell or tissue should be incorporated or rejected.

10. Cell membrane has receptors for certain hormones. The hormone combines with its particular receptors and either changes membrane permeability or activates enzyme adenylate

cyclase to produce cyclic AMP from ATP. cAMP then triggers a set of enzymes to perform a particular function.

11. Membranes have carrier proteins for active transport.

12. Cell membranes contain enzymes for performing certain reaction on their surface, *e.g.*, ATPase (for ATP synthesis and release of energy from ATP), phosphatases, esterases.

13. Certain cell membranes (*e.g.*, plasma membrane in bacteria, thylakoid membranes of chloroplasts, inner mitochondrial membrane) possess electron transport systems.

14. Membrane infolds are used for bulk intake of materials by endocytosis.

15. As microvilli the membrane becomes specialized for absorption of substances.

16. Secretory, excretory and waste products are thrown out by plasma membrane through exocytosis.

17. In nerve cells the cell membrane takes part in transmission of impulses.

18. Plasmalemma provides sheaths for cilia and flagella.

19. Plasma membrane of the cell helps in movement of some cells by either developing undulations (*e.g.*, fibroblasts) or pseudopodia (*e.g.*, *Amoeba*).

Membrane Transport

Passage of substances across biomembranes occur by three methods— passive transport, active transport and bulk transport.

Passive Transport

It is a mode of membrane transport where the cell does not spend any energy nor shows any special activity. The transport is according to concentration gradient. It is of two types, passive diffusion and facilitated diffusion (8.32).

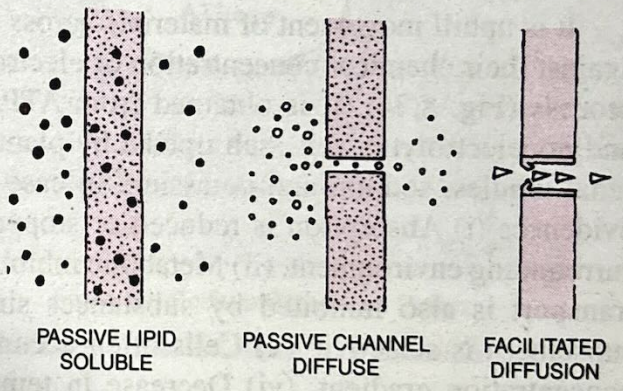

Fig. 8.32. Modes of Passive Transport.

1. **Passive Diffusion or Transport Across Cell Membrane.** Here the cell membrane plays a passive role in the transport of substances across it. Passive diffusion can occur either through lipid matrix of the membrane or with the help of channels.

(i) **Neutral Solutes and Lipid Soluble Substances**. Neutral solutes and fat soluble substances can move across the plasma membrane through simple diffusion along their concentration gradient or from the side of higher concentration to the side of their lower concentration. Based on the free movement of lipid soluble substances across the cell membrane, Overton (1900) proposed that cell membranes are made of lipids.

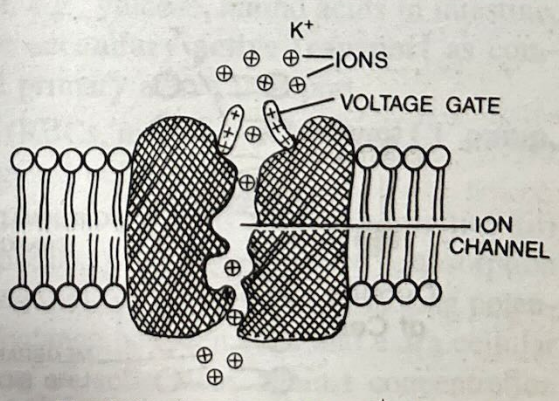

Fig. 8.33. A voltage gated K^+ channel.

(ii) **Open Channel Transport**. Membranes possess some open channels in the form of tunnel proteins. Water channels or aquaporins allow water and water soluble gases (CO_2 and O_2) to pass through according to their concentration gradient. Osmosis is an example of such a transport. **Fil-**

tration is diffusion under pressure across a membrane having minute pores. **Ultrafiltration** or fine filtration occurs during glomerular filtration inside kidneys. **Dialysis** is the process of separating small particles (*e.g.*, crystalline solutes) from larger ones (*e.g.*, colloids) due to difference in the rate of diffusion across a membrane having very minute pores. It is carried out during separation of waste products from blood in artificial kidney.

2. **Facilitated Diffusion**. It occurs through the agency of gated ion channels and permeases. Energy is not required. The transport is along concentration gradient.

(i) **Ion channels** are highly specific. There is a specific channel for each ion. Ions do not pass in dissolved state through ion channels but instead only ions move through them. Most ion channels are **gated** (Fig. 8.33). Depending upon the stimulus required for opening the gates of the ion channels, they are of three types — voltage gated, mechanical gated and ligand gated. More than 100 ion channels have been discovered. Movement through ion channels is according to concentration gradient. The rate of passage is quite high.

(ii) **Permeases.** Permeases function as facilitated pathways for the movement of substances. As a result the rate of transport is stereospecific. Saturation effect is recorded.

(iii) **Cotransport.** It is membrane transport that accompanies active transport of some substance, *e.g.*, glucose (with Na^+). Cotransport is often considered to be part of facilitated diffusion. However, it often occurs against concentration gradient. Therefore, it is part of active transport.

Active Transport

It is uphill movement of materials across the membrane where the solute particles move against their chemical concentration or electro-chemical gradient. Energy is required for the process (Fig. 8.34). It is obtained from ATP. Active transport occurs in case of both ions and nonelectrolytes, *e.g.*, salt uptake by plant cells, glucose and phenolphthalein in case of renal tubules, sodium and potassium in case of nerve cells, etc. It is supported by various evidences (i) Absorption is reduced or stopped with the decrease in oxygen content of the surrounding environment. (ii) Metabolic inhibitors like cyanides inhibit absorption. (iii) Active transport is also inhibited by substances similar to solutes. (iv) Absorption of different substances is selective. (v) Cells often accumulate salts and other substances against their concentration gradient. (vi) Decrease in temperature decreases absorption. (vii) Active transport is more rapid than diffusion. (viii) It shows **saturation kinetics**, that is, the rate of transport increases with increase in solute concentration till a maximum is achieved.

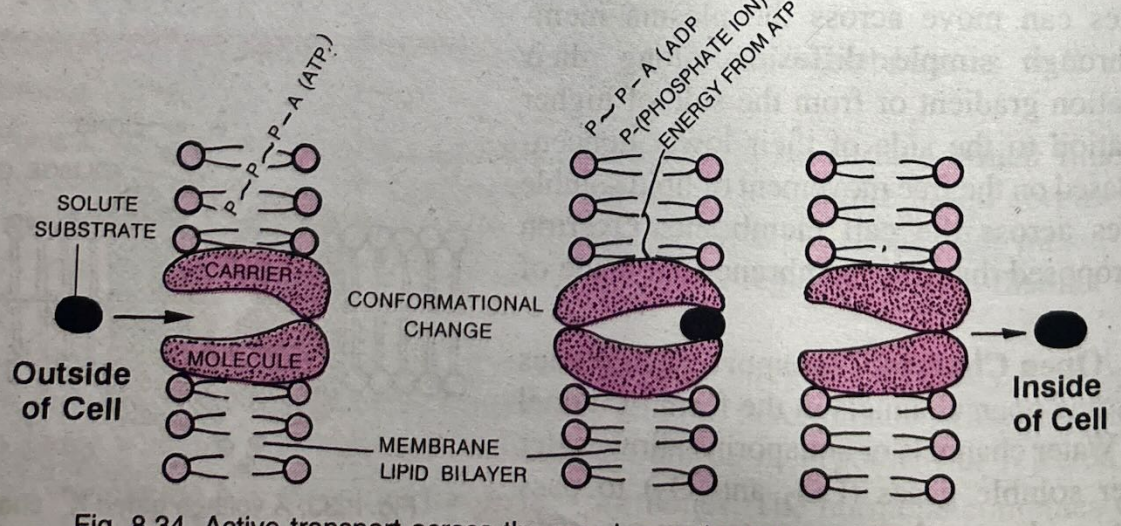

Fig. 8.34. Active transport across the membrane through a carrier molecule.

Beyond this value the rate of membrane transport does not increase indicating that it takes place through the agency of special organic molecules called **carrier molecules, carrier particles** or **carrier proteins**. There is a special carrier molecule for each solute particle (ion or molecule). The carrier has its binding site on two surfaces of the membrane. The solute particle (or substrate) combines with the carrier to form **carrier solute complex**. In the bound state the carrier undergoes a conformational change (Fig. 8.34) which transports the solute to the other side of the membrane. Here the solute is released. Energy is used in bringing about the conformational change in the carrier. It is provided by ATP. In the process ATP is dephosphorylated to form ADP.

Many animal cells operate a **sodium-potassium exchange pump** (Fig. 8.35) at their plasma membrane. A similar proton pump operates in chloroplasts, mitochondria and bacteria. Na^+ — K^+ exchange pump operates with the help of enzyme ATP-ase which also functions as a carrier molecule. The enzyme hydrolyses ATP to release energy. The energy is used in bringing about conformational changes in the carrier. For every ATP molecule hydrolysed, three Na^+ ions are pumped outwardly and two K^+ ions are pumped inwardly. Na^+ — K^+ exchange pump performs the following functions : (i) Maintains a positive potential on the outer side of the membrane and relatively electro-negative potential on the inner side. (ii) The pump creates a resting potential in the nerve cells. (iii) The pump maintains water balance of living cells. (iv) It helps in urine formation. (v) It takes part in excretion of salt as in marine animals. Sea gulls and penguins drink sea water. They excrete excess salt through nasal glands. The nasal salt glands have sodium-potassium pump in the plasma membranes of their cells. Na^+ ions are jumped out actively. Chlorine ions pass out passively. Nasal secretion of the two birds possess 1.5–3.0 times more NaCl concentration than the one present in the blood. (vi) The unsecreted and unmetabolised excess Na^+ ions present in the extra-cellular fluid have a tendency to pass back into the cells. Other substances combine with sodium ions and pass inwardly alongwith them, *e.g.*, glucose, amino acids in intestine. The phenomenon is called **facilitated transport** or **secondary active transport** as compared to Na^+— K^+ exchange pump which is called primary active transport.

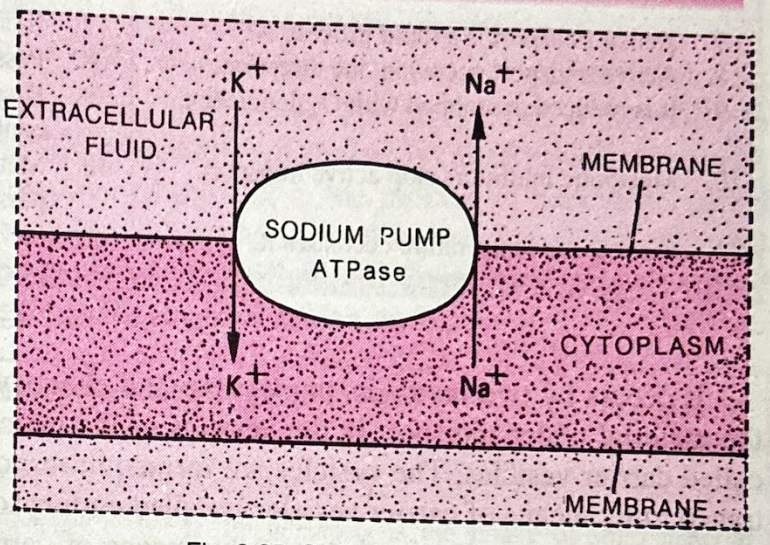

Fig. 8.35. Sodium Potassium Pump.

Other important pumps include **Calcium pump** (RBCs, muscles), **K^+ pump, Cl^- pump, K^+—H^+ exchange pump**. The last one occurs in guard cells.

Active transport is a means of (i) absorption of most nutrients from the intestine (ii) reabsorption of useful material from the uriniferous tubules (iii) rapid and selective absorption of nutrients by cells (iv) maintaining a membrane potential (v) maintenance of resting potential in nerve cells (vi) maintaining water and ionic balance between cells and extra cellular fluid (vii) excretion by salt glands (viii) absorption of substances against concentration gradient.

Differences between Active Transport and Passive Transport (Diffusion)

Active Transport	*Passive Transport*
1. The transport involves an expenditure of energy by the cells.	1. The cells do not spend energy in passive transport.
2. Active transport usually occurs against concentration or electrochemical gradient.	2. Passive transport is always along the concentration or electrochemical gradient.
3. It helps in the accumulation of substances in the cells.	3. Passive transport does not allow accumuation of substances in the cell.
4. Active transport is a vital process.	4. It is a physical process.
5. It requires carrier proteins. Matrix or permeases of the membrane are not involved.	5. Carrier proteins are not involved. It takes place through matrix/channels/permeases.
6. It is highly selective.	6. Passive transport is partly nonselective. All diffusible substances can be transported according to their concentration gradient.
7. Active transport is a rapid process.	7. It is a comparatively slow process.
8. Active transport occurs in one direction.	8. Passive transport is bidirectional.
9. It is reduced or stopped with O_2 deficiency.	9. Passive transport is unaffected by O_2 content.
10. Metabolic inhibitors stop active transport.	10. Metabolic inhibitors do not influence passive transport.
11. Decrease in temperature decreases it.	11. It is not affected by temperature.

Bulk Transport

It occurs by two methods, pinocytosis and phagocytosis. They involve the enclosure of the material under transport in the vesicles of the membrane. The latter are, therefore, also called carrier vesicles. The vesicles are formed in response to chemical stimuli. The inward transport by means of carrier vesicles is called **endocytosis** (Gk. *endon*– within, *kytos*– cell). The outward transport of substances by means of carrier vesicles is known as **exocytosis** (Gk. *exo*– outside, *kytos*– cell). It is quite common in secretory and excretory cells.

Pinocytosis or Potocytosis (Gk. *pinein* or *Potos*– to drink, *kytos*– cell, Fig. 8.36). It is the bulk transport of fluid matter and substances dissolved in it (*e.g.*, ions, sugars, amino acids) across the cell membrane by forming minute detachable vesicles of 100–200 nm diameter. Pinocytosis is also called **cell drinking**. Solute intake may be selective or nonselective. Selective solute intake occurs through specific pits having receptor sites. As soon as solute or **ligand** particles form complexes with receptor sites, plasma membrane invaginates. The invagination deepens and gets pinched off as a vesicle called **pinosome** (Lewis, 1931). The pinosome migrates towards the interior where it liberates the materials

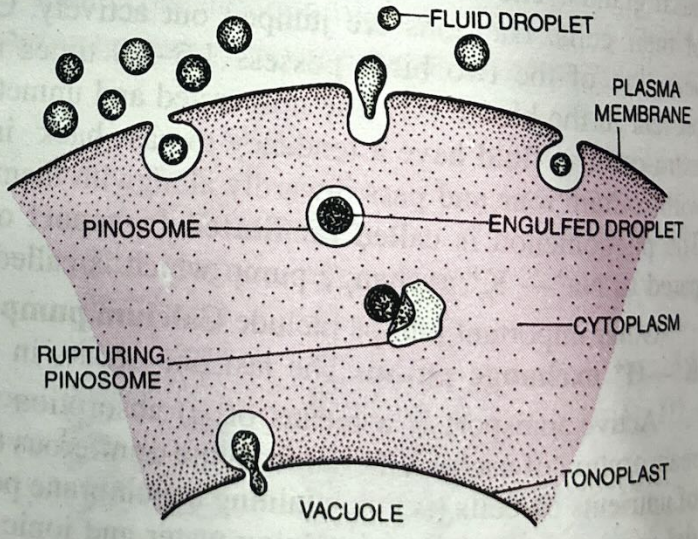

Fig. 8.36. Bulk transport of fluid substances by pinocytosis.

either in the cytoplasm or a vacuole. Lysosomes are required if digestion of solutes is involved. Pinocytosis is quite common in the cell lining the blood capillaries. Macromolecules enter cells only through pinocytosis.

Phagocytosis (Gk. *phagein*– to eat, *kytos*– the cell, Fig. 8.37). It is also called **cell eating**. Phagocytosis is the transport of solid matter like food, foreign particles, pathogens, etc. across the membrane by forming detachable vesicles. These vesicles are called **phagosomes**. They are formed by invagination of plasma membrane in the region of solid particles, rapid evagination on the periphery, formation of a vesicle and pinching off the latter into the interior as **phagosome**. A phagosome is 1–2 μm in diameter. It fuses with a lysosome to produce a **digestive vacuole**. The solid food is digested. The digested food diffuses into the cytoplasm. The vacuole containing the indigestible substances is called **residual vacuole**. The undigested parts are usually thrown out of the cell in the process of exocytosis called **ephagy** or **cell vomiting**. Phagocytosis by some white blood corpuscles is an important defence mechanism of the animal body. Some 100 billion old erythrocytes are destroyed every day in the human body through phagocytosis in spleen and liver.

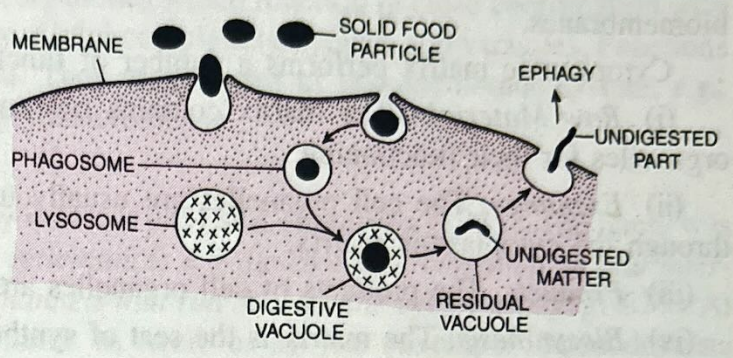

Fig. 8.37. Phagocytosis.

Differences between Pinocytosis and Phagocytosis

Pinocytosis	*Phagocytosis*
1. It is the bulk intake of fluid materials by a cell.	1. Phagocytosis is the intake of solid material from outside to the inside of the cell.
2. Vesicles formed in pinocytosis are small.	2. Vesicles formed in phagocytosis are large.
3. Membrane possesses receptor pits for receiving the materials.	3. Receptor pits are absent.
4. Membrane does not show evagination during pinocytosis.	4. Membrane evaginates on the periphery to engulf the solid particle.
5. Digestion or breakdown of absorbed substances may or may not occur. Accordingly a food vacoule may or may not be formed.	5. A digestive or food vacuole is formed from a phagosome.
6. Lysosomes play no role in utilization of absorbed materials if digestion is not involved.	6. Lysosomes are essential because solid substances taken in by phagocytosis require digestion.
7. There is no exocytosis or ephagy.	7. The undigested parts of the solid particle are thrown out by exocytosis or ephagy.

III. Cytoplasm (Strasburger, 1882)

Cytoplasm is jelly-like semi-fluid general mass of protoplasm excluding the nucleus but including all other components— cytoplasmic matrix, cell organelles and cell inclusions.

(A) Cytoplasmic Matrix or Cytosol (Hyaloplasm)

It is the clear fluid part of the cytoplasm which can exist in two states, **sol** and **gel**. The two are respectively called **plasmasol** and **plasmagel**. Plasmagel is usually present below the

plasma membrane. It is called **ectoplast**. Plasmasol is internal and is known as **endoplast**. Water constitutes 90% of the matrix. Matrix is actually a crystallo-colloidal complex in water where some chemicals are present in the form of a true solution while others are present as colloidal solution, *e.g.*, minerals, sugars, amino acids, tRNAs, nucleotides, vitamins, proteins, enzymes, etc. Proteins are the major colloidal particles of the complex. Fats usually occur as emulsion either in the form of globules in the matrix or as component of various biomembranes.

Cytoplasmic matrix performs a number of functions. Important ones are :

(i) *Raw Materials*. The matrix contains raw materials and provide the same to cell organelles for their functioning.

(ii) *Exchange*. The cell organelles are usually unconnected. They exchange materials through the cytoplasmic matrix.

(iii) *Products*. The products of cell organelles are passed out into the matrix.

(iv) *Biosynthesis*. The matrix is the seat of synthesis of a number of biochemicals like fats, nucleotides, some carbohydrates, proteins, coenzymes, etc.

(v) *Catabolic Activities*. Glycolysis, anaerobic respiration and pentose pathway type of respiration occur in the matrix part of cytoplasm.

(vi) *Distribution*. The cytoplasmic matrix is always in motion. This helps in distribution of various materials inside the cell.

Cytoplasmic Streaming (Amici, 1818). It is an autonomic vital movement that occurs continually in the cytoplasmic matrix of eucaryotic cells. **Cytoplasmic streaming** is also called protoplasmic streaming or **cyclosis**. It is of two types— rotation and circulation. In rotation, the cytoplasmic matrix continuously moves in one direction around a central vacuole, *e.g.*, young leaves of *Hydrilla*. In circulation, the cytoplasmic matrix moves in different directions around different vacuoles of the cell, *e.g.*, staminal hair of *Rhoeo* or *Tradescantia*. Cytoplasmic streaming takes part in (a) movement of organelles inside the cell like chloroplasts in relation to light intensity (b) distribution of various substances in the cell (c) distribution of food vacuoles as in *Amoeba* and *Paramecium* (d) formation of pseudopodia in white blood corpuscles and *Amoeba* (e) quick repair of membrane and other constituents (f) distribution of heat inside the cell.

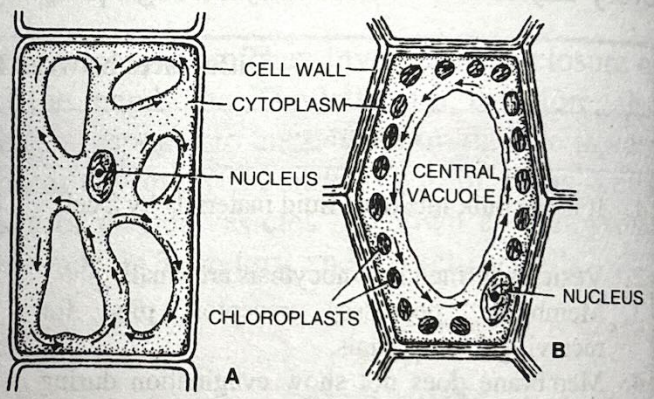

Fig. 8.38. Cyclosis or streaming movement. A, a cell showing circulation type of cyclosis or protoplasmic movement in different directions. B, rotation type of cyclosis or unidirectional protoplasmic movement.

The rate of cytoplasmic streaming or cyclosis depends upon (i) viscosity of cytoplasm, (ii) temperature, (iii) metabolic state of cytoplasm, (iv) presence or absence of aerobic respiration, (v) presence or absence of cytoplasmic poisons, anaesthetics, hormones, etc.

The exact reason for cytoplasmic streaming is not known. There are two possibilities, (a) sol-gel changes (b) movement of microfilaments.

(B) Cell Organelles

They are sub-cellular structures with characteristic morphological forms, distinctive

chemical constitutions and definite functions, which can be carried out by them even outside the cytoplasm provided they are supplied with substances which are normally provided by the cell. A cell contains a number of organelles like mitochondria, plastids (of several types), endoplasmic reticulum, Golgi complex, lysosomes, microbodies, ribosomes, etc.

ENDOMEMBRANE SYSTEM

It is a grouping of some membrane organelles which function in close coordination with one another, *viz.*, endoplasmic reticulum, Golgi complex, lysosomes and vacuoles. Functions of other organelles are not coordinated. They are not part of endomembrane system, *e.g.*, plastids, mitochondria, peroxisomes, glyoxisomes, etc.

1. Endoplasmic Reticulum (ER)

It was discovered independently by Porter (1945) and Thompson (1945). The name was given by Porter in 1953. *Endoplasmic reticulum is a 3-dimensional, complicated and interconnected system of membrane-lined channels that run through the cytoplasm* (Fig. 8.39). At places, it is connected with plasmalemma as well as nuclear envelope. Plasmodesmata contain it in the form of desmotubules. It is not visible under light microscope but can be observed under electron microscope.

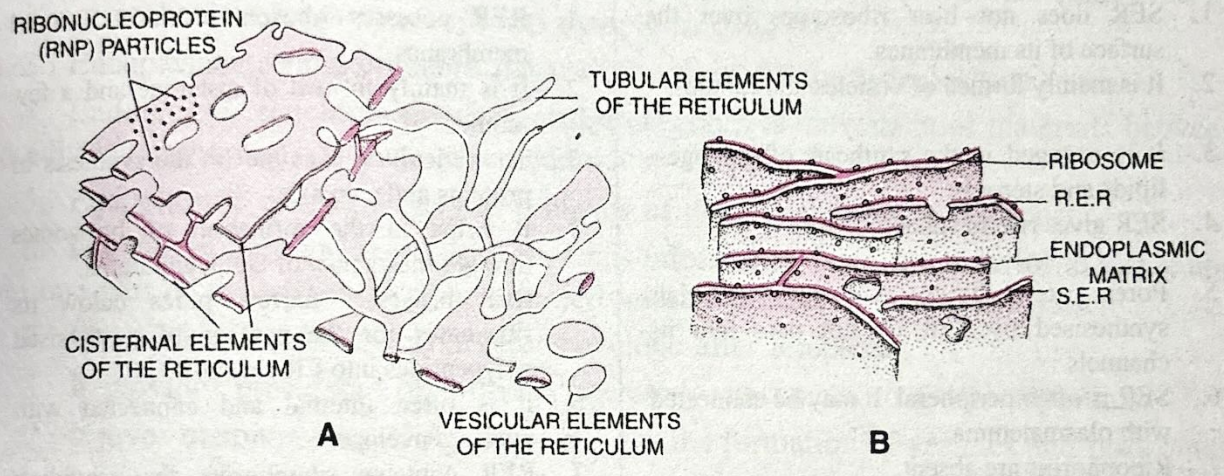

Fig. 8.39 (A&B). Part of endoplasmic reticulum showing its three dimensional nature.

Endoplasmic reticulum divides the intracellular space into two compartments **luminal** (inside the endoplasmic reticulum) and **extra-luminal** (rest of cytoplasm). The extent of endoplasmic reticulum varies from cell to cell. Normally it forms 30–60% of membrane system of the cell which increases the internal surface 30–40 times as compared to external surface. Endoplasmic reticulum is quite extensive in metabolically active cells (*e.g.*, cells of pancreas, liver), simple in storage cells (in the form of tubules in adipose cells), reduced in spermatocytes (in the form of a few vesicles), and absent in eggs, mature erythrocytes, embryonic cells, resting cells, prokaryotic cells, etc.

Types. Depending upon the nature of its membranes, endoplasmic reticulum is of two main types, **smooth** and **rough.** The two types of ER may be continuous with one another, plasma membrane and nuclear envelope. Endoplasmic reticulum may develop from pre-existing E.R., plasmalemma or nuclear envelope.

Smooth Endoplasmic Reticulum (SER). It has smooth membranes which do not bear

ribosomes. It is, therefore, also called **agranular endoplasmic reticulum**. This type of ER is found in cells engaged in the synthesis and storage of glycogen, fat and sterols (*e.g.*, glycogen storing liver cells, interstitial cells, adrenal cortical cells, adipose cells, muscle cells, retinal cells, etc). It is also comsmonly found in leucocytes. Smooth endoplasmic reticulum is mostly made of vesicles and tubules. Sphaerosomes are believed to originate from SER.

Rough Endoplasmic Reticulum (RER). It has rough membranes because a number of ribosomes occur attached to their outer surfaces. RER is, therefore, also called **granular endoplasmic reticulum**. The membrane of the endoplasmic reticulum bears a fine pore in the area of attached ribosome to pass the synthesised polypeptide into the channel of endoplasmic reticulum for transport. RER contains two types of glycoproteins (ribophorin I and ribophorin II) for attachment to ribosomes. On account of the presence of ribosomes, the rough ER is engaged in synthesising proteins and enzymes. It is, rich in cells which are actively engaged in protein synthesis and secretory acitivity, *e.g.*, pancreatic acinus cells, plasma cells, fibroblasts, goblet cells. In conjunction with Golgi apparatus, RER helps to produce lysosomes. RER is mostly made of cisternae. Tubules are very few.

Differences between SER and RER

SER	*RER*
1. SER does not bear ribosomes over the surface of its membranes.	1. RER posesses ribosomes attached to its membranes.
2. It is mainly formed of vesicles and tubules.	2. It is mainly formed of cisternae and a few tubules.
3. It is engaged in the synthesis of glycogen, lipids and steroids.	3. The reticulum takes part in the synthesis of proteins and enzymes.
4. SER gives rise to sphaerosomes.	4. It helps in the formation of lysosomes through the agency of Golgi apparatus.
5. Pores are absent so that materials synthesised by SER do not pass into its channels.	5. RER possesses narrow pores below its ribosomes for the passage of synthesised polypeptides into ER channels.
6. SER is often peripheral. It may be connected with plasmalemma.	6. It is often internal and connected with nuclear envelope.
7. Ribophorins are absent.	7. RER contains ribophorins for providing attachment to ribosomes.
8. It may develop from RER.	8. It may develop from nuclear envelope.
9. It has enzymes for detoxification.	9. The same are absent.
10. Vesicles for *cis-* face of Golgi apparatus are provided by SER.	10. It provides biochemicals for Golgi apparatus.

Structure. Endoplasmic reticulum consists of membrane lined channels or spaces. The hannels or spaces contain a fluid called **endoplasmic matrix**, which is quite different from ytoplasmic matrix present outside the reticulum. The membranes of endoplasmic reticulum re 50–60 Å thick. Endoplasmic reticulum can exist in three forms (Fig. 8.40)— cisternae, esicles and tubules.

1. **Cisternae**. They are flat interconnected sac-like parts of the endoplasmic reticulum hich are 40–50 nm in diameter. The cisternae are found in bundles where they lie parallel one another. They occur in the cells actively involved in synthetic activity.

2. **Vesicles**. They are oval or rounded sacs of 25–500 nm in diameter. The vesicles ppear as small vacuoles. They remain isolated in the cytoplasm. The vesicles are also called **icrosomes**.

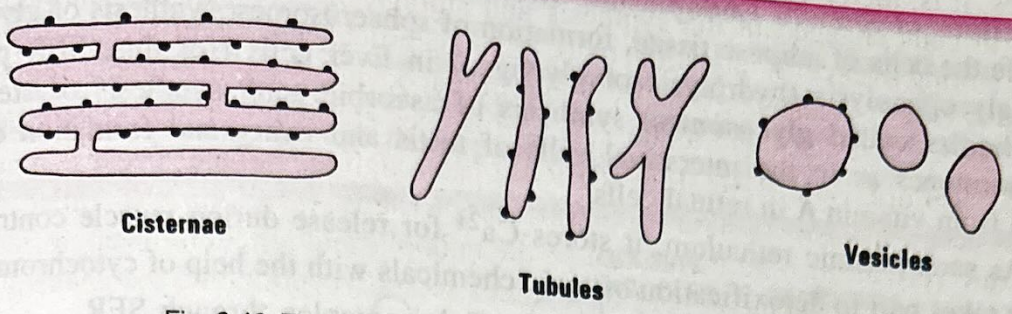

Fig. 8.40. The three components of endoplasmic reticulum.

3. **Tubules**. They are tube-like extensions which may be connected with cisternae or vesicles to form a reticular system. The tubules can be irregular or regular, branched or unbranched with a diameter of 50–100 nm.

FUNCTIONS

Common Functions of ER

1. It provides a large surface inside the cell for various physiological activities.
2. It functions as cytoskeleton or intracellular and ultrastructural skeletal framework by providing mechanical support to colloidal cytoplasmic matrix.
3. Endoplasmic reticulum keeps the various organelles in their position.
4. Endoplasmic reticulum (as **desmotubules**) controls movement of materials between two adjacent protoplasts through plasmodesmata.
5. Endoplasmic reticulum acts as a means of quick intracellular transport.
6. In cells, endoplasmic reticulum conducts information from cell exterior to inside and from one part of the cell to another, *e.g.*, cytoplasm to nucleus and *vice versa*.
7. It provides membranes to nuclear envelope after telophase.
8. It provides precursors of different secretory substances to Golgi apparatus.
9. It gives membranes to Golgi apparatus for the formation of vesicles and lysosomes.
10. It gives rise to vacuoles.
11. Complexing of proteins and lipids to form lipoproteins occur in ER.
12. The membranes of endoplasmic reticulum contain a number of enzymes (*e.g.*, ATP-ase, reductases, dehydrogenases, phosphatases) for various metabolic activities and cytochromes that take part in electron transport.

Functions of Rough Endoplasmic Reticulum (RER)

1. It contains SRP receptors or ribophorins for providing attachment to ribosomes.
2. RER provides a large surface area to ribosomes.
3. It bears enzymes in the region of pores for modifying polypeptides synthesised by attached ribosomes, *e.g.*, glycosylation.
4. It synthesises serum proteins, membrane proteins and a number of other proteins.
5. Proteins and enzymes synthesised by ribosomes enter the channels of RER both for intracellular use as well as secretion.
6. It provides enzyme precursors for the formation of lysosomes by Golgi complex.
7. SER can develop from RER by discarding ribosomes.

Functions of Smooth Endoplasmic Reticulum. (1) It is responsible for synthesis of fats inside the cells of adipose tissue, formation of sphaerosomes, synthesis of glycogen as well as glycogenolysis (hydrolysis of glycogen) in liver cells (for this, SER possesses enzyme bodies called **glycosomes**) synthesis of ascorbic acid, synthesis of sterols and steroid hormones as in the interstitial cells of testis and ovary and formation of visual pigments from vitamin A in retinal cells.

2. As sarcoplasmic reticulum, it stores Ca^{2+} for release during muscle contraction.
3. It takes part in detoxification of toxic chemicals with the help of cytochrome P-450.
4. Synthetic products of RER pass on to Golgi complex through SER.

2. Golgi Apparatus or Golgi Complex

Golgi complex (Golgi Apparatus, Dalton Complex, Apparato Reticulare) is a complex cytoplasmic structure made up of smooth membrane saccules or cisternae, a network of tubules with vesicles and vacuoles, which takes part in membrane transformation, secretion and production of complex biochemicals. It is surrounded by an organelle free cytoplasm called **zone of exclusion** or **Golgi ground substance**. It was first seen by George (1867) but is named after Italian scientist Camillo Golgi, who in 1898 recognised the apparatus as reticular structure (apparato reticulare) near the nucleus. In the nerve cells of barn owl and cat by means of **metallic impregnation** method. Its structure was studied under electron microscope by Dalton and Felix (1954).

Occurrence. Golgi apparatus or complex is absent in prokaryotic cells (PPLO, bacteria and blue-green algae). It is present in all eukaryotic cells except sieve tubes of plants, sperms of bryophytes and pteridophytes and red blood corpuscles of mammals.

Location. In animal cells Golgi complex or apparatus is either single or consists of a single connected complex. The two conditions are respectively called **localised** (most vertebrate cells) and **diffused** (most invertebrate cells, liver and nerve cells of vertebrates). The localised organelle is compact. It generally occurs at one end between the nucleus and the periphery. The diffused organelle is found to form a network, *e.g.*, around the nucleus in nerve cells.

In plant cells, Golgi apparatus is formed of a number of *unconnected units* called **dictyosomes**. Their number is highly variable— from one in certain simple algae to 25000 in rhizoidal cell of *Chara*. Commonly there are 10–20 dictyosomes per plant cell. A liver cell may possess upto 50 units of Golgi apparatus called Golgisomes.

Structure. The shape and size of Golgi complex are not fixed. They depend upon the physiological state of the cells. A typical plant dictyosome is 0.5–1.0 μm in diameter. Usually Golgi complex is made up of four parts— **cisternae, tubules, vesicles** and **vacuoles** (Fig. 8.41).

Cisternae. Golgi complex consists of a stack of generally 4–8 (range 3–20) membrane bound **saccules** or **cisternae**. Unicisternal dictyosomes are found in fungi.

The membranes of the saccules or cisternae are smooth but of variable thickness. They enclose a lumen of 60–90 Å. Lumen contains a fluid substance or matrix. In a stack, the adjacent cisternae are separated by a distance of 100–300 Å. The intercisternal space contains thin layer of cytoplasm having parallel fibrils.

The saccules are frequently curved to give a definite polarity to the Golgi apparatus. One face of the apparatus is convex while the other is concave. The **convex** side is called **forming** (=formative, *cis*-face) face while the **concave** side of the apparatus is known as **maturing face** (*trans*-face). The membranes of the maturing face are 7–8 nm in thickness

while those of the forming face are about 4 nm in thickness. The forming face receives (transitional) vesicles from endoplasmic reticulum. Their contents pass through various cisternae with the help of coated vesicles and intercisternal connectives. They ultimately reach the maturing face where they are budded off as secretion, coated or Golgian vesicles or vacuoles. While passing through the apparatus, biochemicals are variously transformed.

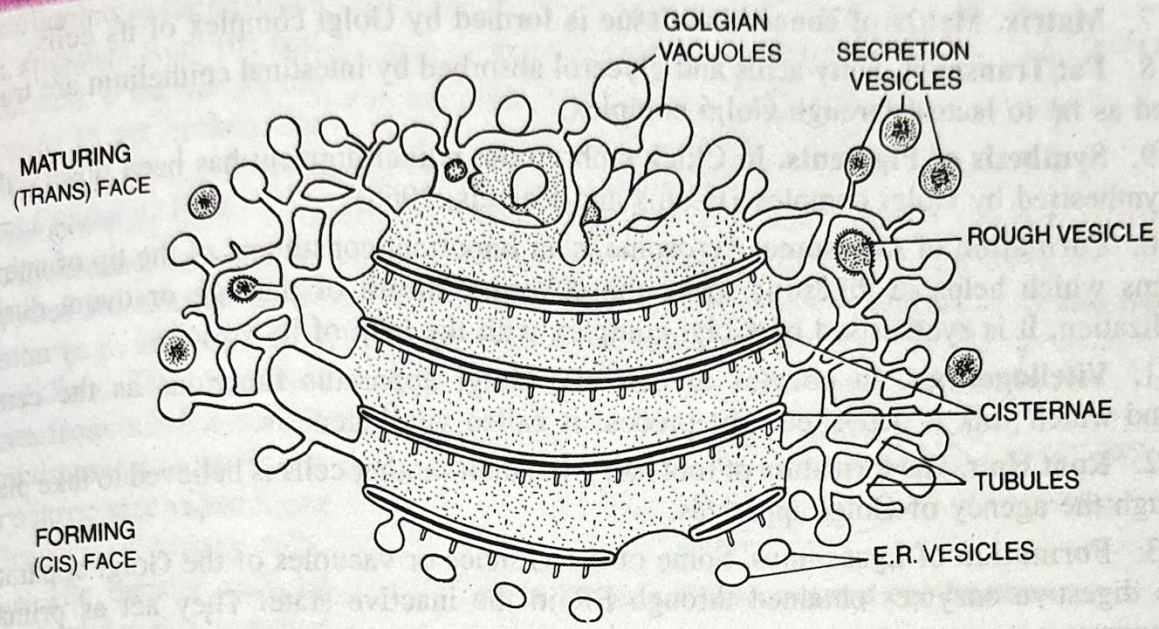

Fig. 8.41. Structure of Golgi apparatus (dictyosome)

Tubules. They form a complicated network towards the periphery and maturing face of the apparatus. Actually tubules arise due to fenestrations of the cisternae. They have a diameter of 30–50 nm. The tubules interconnect the different cisternae.

Vesicles. They are small sacs of 20–80 nm diameter. The vesicles are found attached to the tips of tubules at various levels in the network. They are of two types, **smooth** and **coated**. The coated vesicles have a rough surface. They elaborate membrane proteins. The smooth vesicles have a smooth surface. They contain secretory substances and are hence known as **secretion vesicles.**

Golgian Vacuoles. They are expanded parts of the cisternae which have become modified to form vacuoles. The vacuoles develop from the concave or maturing face. Golgian vacuoles contain amorphous or granular substance. Some of the golgian vacuoles function as lysosomes.

Functions

1. **Secretion.** All glandular cells depend upon Golgi complex for concentrating and packaging their products inside a soluble protein coat visible as dark staining under electron microscope. They are sent out of the cells through **exocytosis** or **reverse pinocytosis**.

2. **Transformation of Membranes.** Golgi complex brings about membrane transformation, that is, converting one type of membrane (*e.g.*, that of ER) into other types (*e.g.*, selectively permeable plasma membrane, differentiated membrane of lysosome). The complex also takes part in the recycling of plasma membrane.

3. **Glycoproteins and Glycolipids.** Proteins synthesised by the rough endoplasmic reticulum and lipids synthesised by smooth endoplasmic reticulum reach the cisternae of the Golgi apparatus. Here, they combine with carbohydrates to form glycoproteins and glycolipids.

4. **Special Simple Carbohydrates.** Sialic acid and galactose are made inside Golgi complex.

5. **Complex Carbohydrates.** Most of the complex carbohydrates, other than glycogen and starch, are synthesised inside the Golgi complex, *e.g.*, pectic compounds, mucopolysaccharides, hyaluronic acid, chondroitin sulphate, hemicellulose, etc.

6. **Hormones.** Production of hormones by endocrine glands is mediated through it.

7. **Matrix.** Matrix of connective tissue is formed by Golgi complex of its cells.

8. **Fat Transport.** Fatty acids and glycerol absorbed by intestinal epithelium are transferred as fat to lacteal through Golgi complex.

9. **Synthesis of Pigments.** In Chick embryo the retinal pigment has been observed to be synthesised by Golgi complex (Beams and Kessels, 1968).

10. **Formation of Acrosome.** Acrosome is an important constituent of the tip of animal sperms which helps in digesting away the covering sheath of the egg or ovum during fertilization. It is synthesised by Golgi complex with the help of its vesicles.

11. **Vitellogenesis.** In oocytes of animals, Golgi apparatus functions as the centre around which yolk is deposited. The process is called vitellogenesis.

12. **Root Hair.** The formation of root hair from their mother cells is believed to take place through the agency of Golgi apparatus.

13. **Formation of Lysosomes.** Some of the vesicles or vacuoles of the Golgi apparatus store digestive enzymes obtained through ER in the inactive state. They act as primary lysosomes.

14. **Hypnotoxin.** Hypnotoxin of nematoblasts is formed by Golgi apparatus.

15. **Formation of Plasmalemma.** Membranes of the vesicles produced by Golgi apparatus join in the region of cytokinesis to produce new plasmlemma.

16. **Formation of New Cell Wall.** Pectic compounds of middle lamella and various polysaccharides of the cell wall are secreted by Golgi complex. They are brought to the area of new wall synthesis by secretion vesicles.

3. Lysosomes

They were discovered accidently by a Belgian scientist, Christian de Duve, in 1955 through fractionation technique. The organelles were observed under electron microscope by Novikoff (1956). He also coined the term, lysosomes.

Lysosomes (Gk. *lysis*– digestive or loose, *soma*– body) *are small vesicles which are bounded by a single membrane and contain hydrolytic enzymes in the form of minute crystalline or semicrystalline granules of 5–8 nm.* About 50 enzymes have been recorded to occur in them. All the enzymes do not occur in the same lysosome but there are different sets of enzymes in different types of lysosomes. The important enzymes are acid phosphatases, sulphatases, proteases, peptidases, nucleases, lipases and carbohydrases. They are also called **acid hydrolases** because these digestive enzymes usually function in acidic medium or *p*H of 4–5. Acidic conditions are maintained inside the lysosomes by pumping of H^+ or protons into them. The covering membrane of lysosomes keeps the hydrolytic enzymes out of contact from the cellular contents. It is itself protected from them by high glycosylation of its proteins and lipids. The covering membrane becomes fragile in the absence of the oxygen, or the presence of excess of vitamins A and E, male and female hormones, bile salts, carcinogens, silica, asbestos particles, heat, many drugs, X-rays and ultra-violet rays. The membrane is protected from these agencies by cortisone, cortisol, chloroquine and a type

of cholesterol. Lysosomes are called **suicide bags** because of the presence of a large number of digestive enzymes or acid hydrolases in them. Only a thin membrane separates the destructive enzymes from the rest of the cell. If the membrane happens to get broken, the various cellular constituents would undergo lysis.

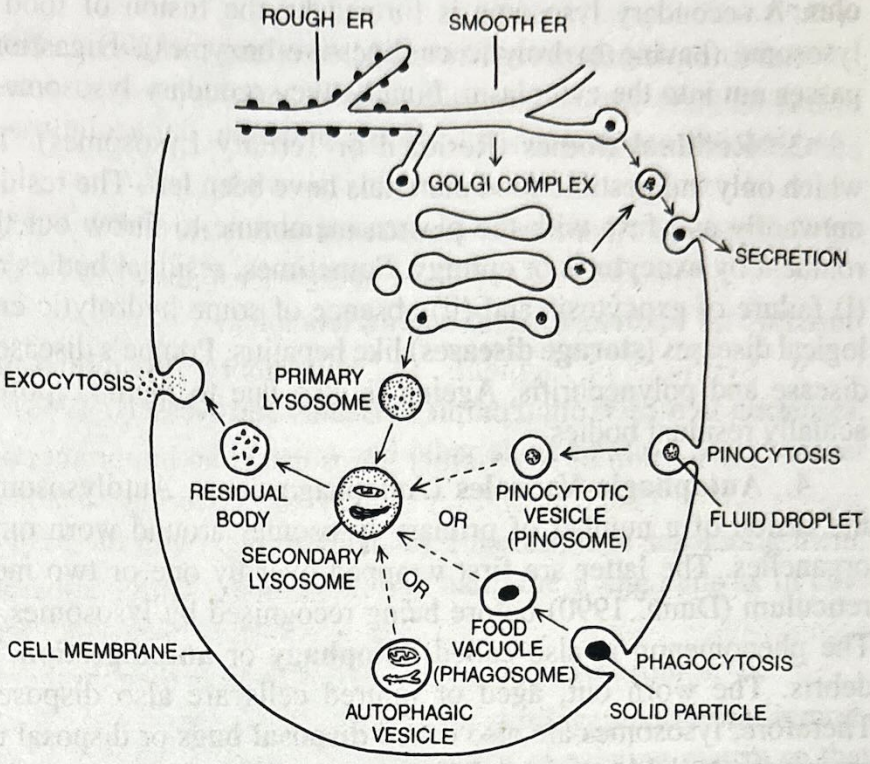

Fig. 8.42. Types of lysosomes and their functions.

Lysosomes are generally rounded but can be irregular (*e.g.*, root tip cells) in outline. The diameter varies from 0.2–0.8 μm but sometimes it may grow to a very large size (upto 5 μm in leucocytes, kidney cells, etc.). The interior may be almost solid or differentiated into outer denser region and a central less dense mass with granular content. Lysosomes occur in all animal cells with the exception of red blood corpuscles. In plants and fungi, their function is taken over by vacuoles. In animals, lysosomes are abundant in leucocytes, macrophages, Kupffer's cells and similar cells with phagocytic activity.

Lysosomes are believed to be formed by the joint activity of endoplasmic reticulum endosomes and Golgi complex (GERL system). The precursors of hydrolytic enzymes are mostly synthesised at the rough endoplasmic reticulum. The latter transfers them to the forming face of Golgi complex either directly or from smooth endoplasmic reticulum through its vesicles. In Golgi complex the precursors are changed to enzymes. The enzymes are then packed in larger vesicles which are pinched off from the maturing face. **Golgian** vesicles are joined by endosomes to produce lysosomes (Machamer, 1993).

Lysosomes do not normally burst in the cytoplasm. All materials which are to be acted upon by lysosome enzymes must enter them. Rather the mateials are usually enclosed inside vacuoles and the vacuoles fuse with the lysosomes for digestion of materials. Lysosomes take part in intracellular digestion of various types of materials of endogenous or exogenous origin. Extracellular digestion can be performed by them under certain conditions. They help in removing various toxic substances including carcinogens.

Lysosomes pass through various stages in the same cell. The phenomenon is called **polymorphism** or existence of more than one morphological form. Depending upon their morphology and function, there are four types of lysosomes— primary, secondary, residual bodies and autophagic vacuoles (Fig. 8.42).

1. **Primary Lysosomes.** They are newly pinched off vesicles from the Golgi apparatus which generally fuse with some endosomes to become fully functional. The primary lysosomes are small in size. They contain hydrolytic enzymes in the form of granules.

2. **Secondary Lysosomes.** They are also called **heterophagosomes** or **digestive vacuoles**. A secondary lysosome is formed by the fusion of food containing phagosome with lysosome (having hydrolytic or digestive enzymes). Digestion occurs. The digested food passes out into the cytoplasm. Finally, the secondary lysosome is left with undigested food.

3. **Residual Bodies** (Residual or Tertiary Lysosomes). They are those lysosomes in which only indigestible food materials have been left. The residual bodies or lysosomes pass outwardly and fuse with the plasma membrane to throw out the debris into external environment by **exocytosis** or **ephagy**. Sometimes, residual bodies remain inside the cells due to (i) failure of exocytosis and (ii) absence of some hydrolytic enzymes. This leads to pathological diseases (**storage diseases**) like hepatitis, Pompe's disease, Hurler's disease, Tay-Sachs disease and polynephritis. Ageing is also due to them. Lipofuschin pigment granules are actually residual bodies.

4. **Autophagic Vacuoles** (Autophagosomes, Autolysosomes). They are produced by the fusion of a number of primary lysosomes around worn out or degenerate intracellular organelles. The latter are first wrapped over by one or two membranes from endoplasmic reticulum (Dunn, 1990) before being recognised by lysosomes. The cell debris is digested. The phenomenon is also called **autophagy** or **autodigestion**. It helps in disposal of cell debris. The worn out, aged or injured cells are also disposed of similarly (apoptosis). Therefore, lysosomes are also called **disposal bags** or disposal units. The digested products are made available to the cell for new synthesis. Lysosomes are, therefore, also known as **recycling centres**. Besides removing worn out organelles, old or diseased cells, the autophagic vacuoles are also used in removing internal obstructions. Autophagic vacuoles provide nourishment during starvation (de Duve, 1967).

Autolysis. It is self destruction of a cell, tissue or organ with the help of lysosomes. Lysosomes performing autolysis do not enclose the structures to be broken down. Instead, they themselves burst to release the digestive enzymes. Autolysis occurs in ageing, dead or diseased cells. The disappearance of larval organs during metamorphosis (*e.g.*, tail in frog) is due to autolysis.

Functions

1. **Intracellular Digestion.** Individual cells may obtain food through phagocytosis. The same is digested with the help of lysosomes.

2. **Extracellular Digestion.** For this the lysosomes release enzymes in the external environment through exocytosis.

3. **Body Defence.** Lysosomes of leucocytes devour foreign proteins, toxic substances, bacteria and other microorganisms. They thus take part in natural defence of the body.

4. **Autophagy.** In the metamorphosis of many animals (*e.g.*, amphibians, tunicates) certain embryonic parts like tail, gills, etc. are digested through the agency of lysosomes. The digested food is used in the growth of other parts.

5. **Removal of Obstructions.** Obstructing structures are destroyed by lysosomes.

6. **Mobilisation of Reserves.** During periods of starvation, lysosomes provide nourishment by rapidly hydrolysing the organic foods stored in the cells (carbohydrates, fats and proteins). Hobilisation of reserve food during germination of seeds is also accomplished by lysosomes. Extra nourishment may also be got by digesting some organelles and cells.

7. **Intracellular Scavenging.** In long lived cells the lysosomes perform intracellular scavenging by removing old or useless organelles.

8. **Sperm Lysins.** They are lysosomal enzymes which are used for breaking limiting membrane of eggs.

9. **Disposal of Useless Cells.** They cause breakdown of ageing and dead cells.

10. **Storage Diseases.** In certain regions due to some malfunction, the residual bodies do not undergo exocytosis. Instead, they remain inside the cells and cause disease, *e.g.*, hepatitis, polynephritis.

11. **Formation of Thyroxine.** In thyroid, active hormone thyroxine is formed through hydrolysis of thyroglobulin by the agency of lysosomes.

12. **Cell Division.** Lysosomes seem to be essential for cell division perhaps by overcoming agents that cause repression of mitotic cycle.

13. **Genetic Changes.** They may harm genetic material through the release of nucleases. It may result in mutations, breakage of chromosomes and other abnormalities. Blood cancer may be result of such an activity.

14. **Carcinogenesis.** Lysosomes remove carcinogens by engulfing and separating them. However, when the carcinogen is in excess, lysosome may harm the living cells as in case of lung fibrosis caused by silicosis or asbestosis.

15. **Leucocyte Granules.** Leucocyte granules are derived from lysosomes.

16. **Osteogenesis.** At the time of formation of bones from cartilage and during remodelling of the bone, lysosomes of the osteoclasts cause breakdown of existing matrix so that it may be replaced by the new one.

4. Vacuoles

Vacuoles are non-cytoplasmic areas present inside the cytoplasm which are separated from the latter by specific membranes. Vacuoles are believed to be formed by expansion and pinching off from ER. Depending upon the contents and functions, vacuoles are of four types— sap vacuoles, contractile vacuoles, food vacuoles and air vacuoles.

(i) **Sap Vacuoles**. They are fluid filled vacuoles or vesicles which are separated from the cytoplasm by a selectively permeable membrane called **tonoplast**. It has a number of transport systems for the passage of different substances. A number of small sap vacuoles occur in animal cells and young plant cells. In mature plant cells, the small vacuoles fuse to form a single large central vacuole which occupies upto 90% of the volume of the cell. The large central vacuole spreads the cytoplasm in the form of a thin peripheral layer. This is a device to facilitate rapid exchange between cytoplasm and the surrounding environment.

The fluid present in the sap vacuoles is often called **sap** or vacuolar sap. It contains mineral salts, sugars, amino acids, esters, proteins, waste products and water soluble pigments called anthocyanins. Some crystalline deposits may also occur. (i) Tonoplast has sites for passage of a number of ions and other materials into vacuole against their concentration gradient. (ii) They may store food reserve, *e.g.*, sucrose. (iii) Solutes present in cell sap maintain a proper osmotic pressure in the cell for its turgidity and water absorption. (iv) They play an important role in cell enlargement. (v) The sap vacuoles store and concentrate waste products. The same are segregated from the living part of the cell. (vi) Water soluble pigments provide colouration to the cell. The most common water soluble vacuolar pigments are **anthocyanins** (red, blue, purple) and **anthoxanthins** (ivory to deep yellow). They provide colouration to flowers in Rose, Violet, Dahlia, etc. The pigments attract pollinating and dispersing agencies. They also absorb light radiations passing through them so that their intensity is decreased. (vii) Some plant vacuoles have special transport proteins, an acidic *p*H, a battery of hydrolytic enzymes and function as lysosomes. (viii) Tannins are stored in

vaculoes, cytoplasm and cell walls. (ix) Latex is stored in vaculoes or vacuolar canals. (x) Alkaloids and tannins stored in vaculoes provide protection against herbivores.

(ii) **Contractile Vacuoles**. They occur in some protistan and algal cells found mostly in fresh water. A contractile vacuole has a highly extensible and collapsible membrane. It is also connected to a few feeding canals (*e.g., Paramecium*). The feeding canals obtain water with or without waste products from the surrounding cytoplasm. They pour the same into the contractile vacuole. The vacuole swells up. The process is called **diastole**. The swollen contractile vacuole comes in contact with plasma membrane and collapses. Collapsing is called **systole**. This throws the vacuolar contents to the outside. Contractile vacuoles take part in osmoregulation and excretion. Osmoregulation is required in fresh water habitats where water has tendency to enter the living cells. Due to the presence of higher osmotic concentration in the latter, continued entry of water shall cause bursting of the cells. This is prevented by throwing the extra water to the outside with the help of contractile vacuoles.

(iii) **Food Vacuoles**. They occur in the cells of protozoan protists, several lower animals and phagocytes of higher animals. A food vacuole is formed by fusion of phagosome and a lysosome. The food vacuole contains digestive enzymes with the help of which nutrients are digested. The digested materials pass out into the surrounding cytoplasm.

(iv) **Air Vacuoles** (Pseudovacuoles, Gas vacuoles). They have been reported only in prokaryotes. An air vacuole is not a single entity, neither it is surrounded by a common membrane. It consists of a number of smaller submicroscopic vesicles. Each vesicle is surrounded by a protein membrane and encloses metabolic gases. Air vacuoles not only store gases but provide buoyancy, mechanical stength and protection from harmful radiations.

MITOCHONDRIA

Mitochondria are cell organelles of aerobic eukaryotes which take part in oxidative phosphorylation and Krebs cycle of aerobic respiration. They are called **power houses** of cell because they are the major centres of release of energy in the aerobic respiration. They were first observed by Kolliker in 1850. Benda (1897) gave the present name of mitochondria (Gk. *mitos*– thread, *chondrion*– grain) to the organelles. Mitochondria can be stained differentially with Janus Green and are easily distinguishable under light microscope though ultrastructure can be studied only under electron microscope.

Mitochondria are absent in prokaryotes and anaerobic eukaryotes. Mitochondria are secondarily lost in the red blood corpuscles of mammals. Their number varies from one in some algae (*e.g., Microasterias, Chlorella*), 25 in a sperm cell, 300–400 in a kidney cell, 500–1000 in liver cell, 30,000 in some oocytes, 50,000 in giant amoeba named *Chaos chaos* and 500,000 in flight muscle cells. The number depends upon cellular activities. Cells of dormant seeds have very few mitochondria. Those of germinating seeds have several mitochondria. In general green plant cells contain less number of mitochondria as compared to nongreen plant cells and animal cells.

The position of mitochondria in a cell depends upon the requirement of energy and amino acids. In unspecialised cells they are randomly distributed throughout the cytoplasm. In absorptive and secretory cells, they lie in the peripheral cytoplasm. During nuclear division, more of mitochondria come to lie around the spindle. Mitochondria are more abundant at the bases of cilia or flagella to provide them energy for movements. In muscle fibres they occur in rows in the regions of light bands in between the contractile elements.

Shape and Size

Mitochondria differ in shape— spherical (*e.g.,* Yeast), cylindrical, sausage-shaped, tu-

bular or filamentous. In *Chlorella* the single mitochondrion is tubular and branched. The shape is also controlled by physiological conditions of the cells. Rather they are regularly changing their shape, even fusing and then separating (Alberts *et al*, 2002). Commonly mitochondria are cylindrical in outline. The size of the mitochondria is variable. Normally, they have a length of 1.0–4.1 μm and a diameter of 0.2–1.0 μm (average 0.5 μm).

Chemical Composition. **Proteins.** 60–70%, **Lipids** 25–35%, **RNA** 5–7%, **DNA.** Small quantity. **Minerals**. Traces, Granules Manganese and Calcium phosphate.

Ultrastructure

A mitochondrion contains two membranes and two chambers, outer and inner (Fig. 8.43). The two membranes form the envelope of the mitochondrion. Each of them is 60–75Å in thickness.

Outer Membrane. The membrane is smooth. It is permeable to a number of metabolites. It is due to presence of protein channels called porins or minute pores. A few enzymes connected with lipid synthesis are located in the membrane. It is poorer in proteins as compared to inner membrane.

Inner Membrane. It is permeable to only some metabolites. It is rich in double phospholipid called cardiolipin (having four fatty acids) which makes the membrane impermeable to ions. Protein content is also high, being 70–75% of total components. The inner membrane is infolded variously to form involutions called **cristae**. They are meant for increasing the physiologically active area of the inner membrane. The cristae are generally arranged like baffles, at right angles to the longitudinal axis of the mitochondrion. They are tubular (most plant cells) or plate like (most animal cells) or vesicle-like (*e.g., Euglena*). A crista encloses a space that is continuation of the outer chamber. The density of cristae indicates the intensity of respiration.

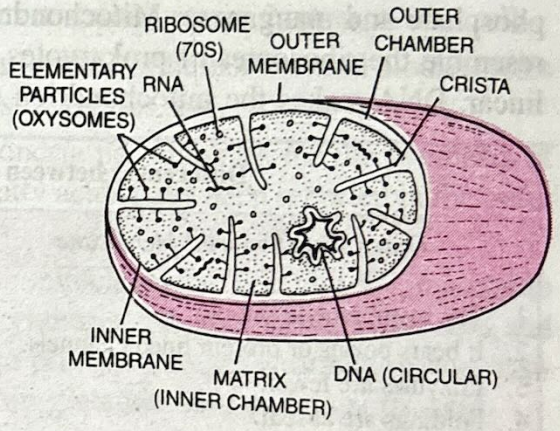

Fig. 8.43. Structure of a mitochondrion. A, mitochondrion partly cut open to show internal and external structure.

The inner membrane as well as its cristae possess small tennis-racket like particles called **elementary particles**, $F_0 - F_1$ particles or oxysomes (= oxisomes). A mitochondrion contains $1 \times 10^4 - 1 \times 10^5$ elementary particles (Fig. 8.44 A). Each elementary particle, $F_0 - F_1$ particle or oxysome has a head, a stalk and a base (Fig. 8.44 B). The base (F_0 subunit) is about 11 nm long and 1.5 nm in thickness. The stalk is 5 nm long and 3.5 nm broad. The head (F_1 subunit) has diameter of 8.5 nm. Elementary

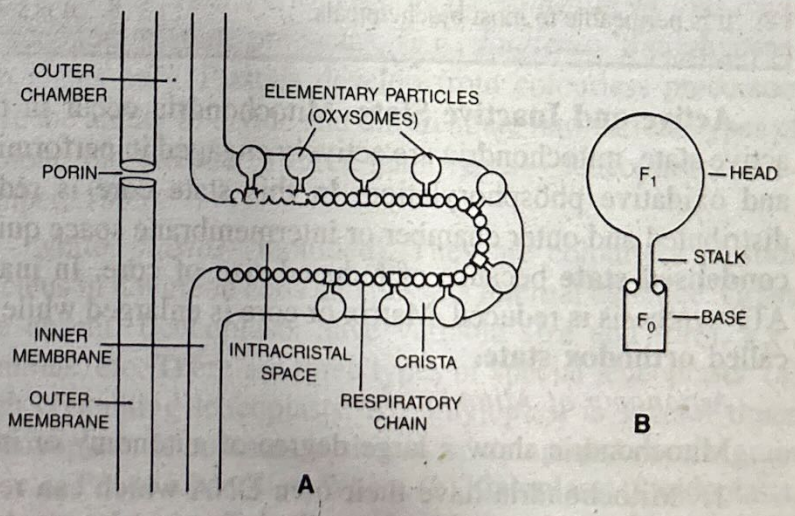

Fig. 8.44. A, inner membrane with elementary particles. B, elementary particle.

particles function as ATP-ase. They are, therefore, the centres of ATP synthesis during oxidative phosphorylation. Both head and stalk constitute F_1. F_0 or base has a roter and a stator. A channel occurs between roter and stator for passage of protons (H^+). Stator is connected to head region by an arm. Enzymes of electron transport are located in the inner membrane in contact with elementary particles.

At places, outer and inner mitochondriai membranes come in contact. They are called **adhesion sites**. Adhesion sites are special permeation regions of the mitochondrion for transfer of materials from outside to inside and *vice versa*.

Outer Chamber (Peri-mitochondrial Space). The chamber is the space that lies between the outer and inner membrane of the mitochondrial envelope. Usually, it is 60–100 Å wide. It extends into the spaces of the cristae (Fig. 8.44 A). The chamber contains a fluid having a few enzymes.

Inner Chamber. It forms the core of the mitochondrion. The inner chamber contains a semi-fluid **matrix**. The matrix has protein particles, ribosomes, RNA, DNA (mitochondrial or mDNA), enzymes of Krebs or TCA cycle (except succinate dehydrogense which is membrane based), amino acid synthesis and fatty acid metabolism, crystals of calcium phosphate and manganese. Mitochondrial ribosomes are 55 S to 70 S in nature. They thus resemble the ribosomes of prokaryotes. DNA is naked. It is commonly circular but can be linear. DNA makes the mitochondrion semi-autonomous.

Differences between Outer and Inner Mitochondrial Membranes

Outer Mitochondrial Membrane	*Inner Mitochondrial Membrane*
1. The membrane is smooth.	1. It contains a number of particles.
2. It bears porins or protein lined channels.	2. It bears carrier and other transport proteins.
3. Enzymes are fewer.	3. It contains a number of enzymes.
4. Foldings are absent.	4. Inner mitochondrial membrane develops a large number of infoldings called cristae.
5. Protein content is roughly equal to that of lipids.	5. Protein content is quite high (upto 80%) while lipid content is low.
6. Cholesterol and other lipids are present. Cardiolipins are absent.	6. Cardiolipins occur.
7. Electron transport system (ETS) is absent.	7. ETS present in inner membrane.
8. It is permeable to most biochemicals.	8. It is selectively permeable.

Active and Inactive State. Mitochondria occur in two states, active and inactive. In active state, mitochondria are actively engaged in performing Krebs cycle, electron transport and oxidative phosphorylation. In this state core is reduced, cristae are more randomly distributed and outer chamber or intermembrane space quite large. Active state is also called **condensed state** because of reduced size of core. In inactive state, respiratory chain and ATP synthesis is reduced. Matrix or core is enlarged while outer chamber is narrow. It is also called **orthodox state**.

Autonomy of Mitochondria

Mitochondria show a large degree of autonomy or independence in their functioning.

1. Mitochondria have their own DNA which can replicate independently.
2. Mitochondrial DNA produces its own mRNA, tRNA and rRNA.
3. The organelles possess their own ribosomes.

4. Mitochondria synthesise some of their own structural proteins. However, most of the mitochondrial proteins are synthesised under instructions from cell nucleus.

5. The organelles synthesise some of the enzymes required for their functioning.

6. They grow internally.

7. New mitochondria develop by division/binary fission of pre-existing mitochondria.

However, mitochondria are not fully autonomous. Both their structure and functioning are partially controlled by nucleus of the cell and availability of materials from cytoplasm. Mitochondria are believed to be symbionts (Margulis, 1971) in the eucaryotic cells which became associated with them quite early in the evolution.

Functions

1. Mitochondria are miniature biochemical factories where food stuffs or respiratory substrates are completely oxidised to carbon dioxide and water. The energy liberated in the process is initially stored in the form of reduced coenzymes and reduced prosthetic groups. The latter soon undergo oxidation and form energy rich ATP. ATP comes out of mitochondria and helps perform various energy requiring processes of the cell like muscle contraction, nerve impulse conduction, biosynthesis, membrane transport, cell division, movement, etc. Because of the formation of ATP, the mitochondria are called **power houses** of the cell.

2. Mitochondria provide important intermediates for the synthesis of several biochemicals like chlorophyll, cytochromes, pyrimidines, steroids, alkaloids, etc.

3. The matrix or inner chamber of the mitochondria has enzymes for the synthesis of fatty acids. Enzymes required for the elongation of fatty acids have been reported in the outer mitochondrial chamber.

4. Synthesis of many amino acids occurs in the mitochondria. The first formed amino acids are glutamic acid and aspartic acid. They are synthesised from a-ketoglutaric acid and oxaloacetic acid respectively. Other amino acids are produced by transformation and transamination or transfer of amino group ($—NH_2$) from glutamic acid and aspartic acid.

5. Mitochondria may store and release Calcium when required.

6. An organism generally receives mitochondria from its mother (maternal inheritance).

PLASTIDS

The term plastid was introduced by E. Haeckel in 1866. *Plastids are semi-autonomous organelles having DNA and double membrane envelope which store or synthesise various types of organic compounds*. With the exception of some protistans, (*e.g., Euglena,* dinophyceae, diatoms) plastids are restricted to plants only. Plastids develop from colourless precursors called **proplastids**. Proplastids have the ability to divide and differentiate into various types of plastids. Depending upon their colour, plastids are of three main types— leucoplasts, chromoplasts and chloroplasts (Schimper, 1883).

(i) **Leucoplasts** (Gk. *leucos*– white, *plastos*– moulded). They are colourless plastids which generally occur near the nucleus in nongreen cells and possess internal lamellae. Grana and photosynthetic pigments are absent. Leucoplasts have variable size and form, *e.g.*, rounded, oval, cylindrical, filamentous, etc. There are three types of special leucoplasts. (a) **Amyloplasts**. They are the starch containing leucoplasts. An amyloplast is several times larger than the original size of leucoplast. It contains a simple or compound starch grain covered by a special protein sheath, *e.g.*, Potato tuber, Rice, Wheat. (b) **Elaioplasts** (Lipidoplasts, Oleoplasts). The colourless plastids store fat, *e.g.*, Tube Rose. (c) **Aleuroplasts, Proteoplasts** or **Proteinoplasts**. The plastids contain protein in the amorphous, crystalloid or crystalloglobоid state (*e.g.*, aleurone cells of Maize grain, endosperm cells of Castor).

(ii) **Chromoplasts** (Gk. *chroma*– colour, *plastos*– moulded). The plastids are yellow or reddish in colour because of the presence of carotenoid pigments. Chlorophylls are absent. Chromoplasts are formed either from leucoplasts or chloroplasts. Lamellae degenerate partially or completely during chromoplast formation. Change of colour from green to reddish during the ripening of Tomato and Chilli is due to transformation of chloroplasts to chromoplasts. The orange colour of Carrot roots is due to chromoplasts. The pigments are often found in crystallised state so that the shape of the plastids can be like needles, spindles or irregular. (i) Chromoplasts provide colour to many flowers for attracting pollinating insects. (ii) They provide bright red or orange colour to fruits for attracting animals for dispersal. (iii) They are also the site of synthesis of membrane lipids.

(iii) **Chloroplasts** (Gk. *chloros*– grass green, *plastos*– moulded). They are greenish plastids which possess photosynthetic pigments, chlorophylls and carotenoids, and take part in the synthesis of food from inorganic raw materials in the presence of radiation energy. Chloroplasts of algae other than green ones are called **chromatophores** (*e.g.*, **rhodoplasts** of red algae, **phaeoplasts** of brown algae).

Differences between Leucoplasts and Chromoplasts

Leucoplasts	*Chromoplasts*
1. They are colourless plastids.	1. Chromoplasts are orange-red plastids.
2. Leucoplasts usually occur in unexposed parts of plants.	2. They are commonly found in exposed parts like flowers and fruits.
3. Internal lamellae are present.	3. Internal lamellae degenerate.
4. They take part in storage of various substances like starch (amyloplasts), fat (elaioplasts) and protein (aleuroplasts).	4. Chromoplasts are rich in carotenoid and lipids.
5. The shape is more regular, mostly rounded.	5. The shape is irregular and having angles due to crystallisation of pigments.
6. They can change to other types of plastids.	6. They do not get changed to other types.
7. Leucoplasts do not attract animals as they are colourless.	7. Being coloured, chromoplasts attract animals for pollination and fruit dispersal.

Number. The number of chloroplasts per cell of algae is usually fixed for a species. The minimum number of one chloroplast per cell is found in green alga *Ulothrix* and several species of *Chlamydomonas*. However, different species of a genus may have different number of chloroplasts, *e.g.*, 1 in *Spirogyra indica* and 16 in *S. rectospora*. A photosynthetic leaf chlorenchyma cell has 20–40 chloroplasts. An internodal cell of *Chara* (an alga) has several hundred chloroplasts.

Shape. In algae the chloroplasts have various shapes. They may be plate like (*e.g.*, *Ulothrix*), cup-shaped (*e.g.*, *Chlamydomonas*), ribbon-like (*e.g.*, *Spirogyra*), polygonal or stellate (*e.g.*, *Zygnema*) and reticulate (*e.g.*, *Oedogonium*). The chloroplasts of higher plants are generally disc-shaped with oval or circular outline. Rarely, they may be lens-shaped, rounded or club-shaped.

Size. Like shape, the size of the chloroplasts is different in different species. The discoid chloroplasts of higher plants are 4–10 μm in length and 2–4 μm in breadth. The size is generally larger in case of polyploid cells as compared to diploid and haploid cells. Normally it is much smaller than that of the cell. However, in many algae the chloroplast may occupy almost the whole length of the cell, *e.g.*, *Spirogyra*. The chloroplast of *Spirogyra* may reach a length of 1 mm.

Chemical Composition. Protein– 50–60%. Lipids– 25–30%. Chlorophyll– 5–10%. Carotenoids (carotenes and xanthophylls)– 1–2%. DNA– upto 0.5%. RNA– 2–3%. Vitamins K and E, quinones, Mg, Fe, Co, Mn, P, etc.– in traces.

Ultrastructure (Fig. 8.45–8.46)

A chloroplast has three parts— envelope, matrix and thylakoids. Pyrenoid and stigma are two additional structures present in the chloroplasts of some algae.

Chloroplast Envelope. A chloroplast is covered by an envelope made up of two smooth membranes. Each membrane is about 90–100 Å thick. It has trilaminar lipoprotein structure. The two membranes are separated by an **intermembrane space** of 100–200 Å width. The outer membrane may be attached to endoplasmic reticulum. At places the inner membrane is connected to thylakoids. As in mitochondria, the outer membrane is more permeable than the inner membrane. The inner membrane has more of proteins including carrier proteins.

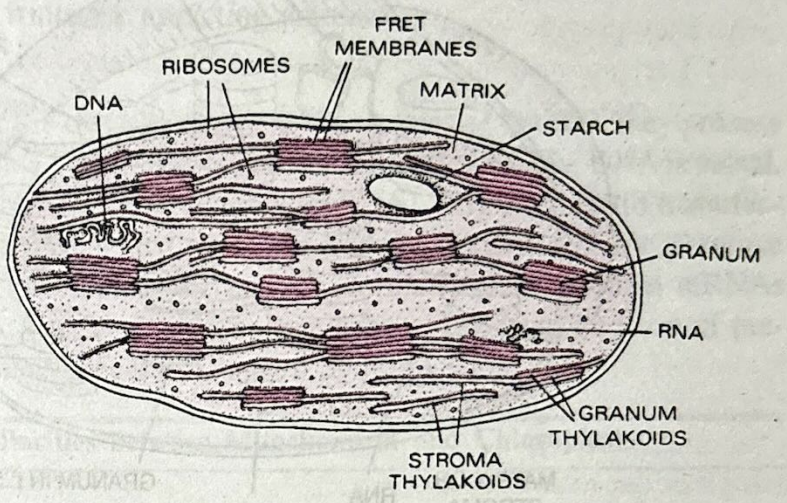

Fig. 8.45. Internal structure of chloroplast of higher plants as seen under electron microscope.

Matrix. The ground substance of a chloroplast is known as **matrix** or **stroma**. It is semifluid colloidal complex that is made of 50% soluble proteins. The remaining is DNA, RNA, ribosomes, plasto-globuli and enzymes. Chloroplast or cpt DNA is naked, circular or occasionally linear. A chloroplast may have several copies of it. DNA makes the chloroplast genetically autonomous because it can both replicate and transcribe to form RNA. Chloroplast ribosomes are 70 S. They resemble the ribosomes of prokaryotes. With the help of ribosomes the chloroplast is able to synthesize most of the enzymes required by it. The important enzymes present in chloroplast are those that take part in synthesis of photosynthetic pigments, photolysis of water, photophosphorylation, dark assimilation of CO_2, synthesis and degradation of starch, synthesis of lipids, etc. Plastoglobuli are lipid droplets of 10–500 nm diameter. They may contain some enzymes, vitamin K and quinones. The chloroplast matrix of higher plants may store starch temporarily, as starch grains. It is known as **assimilation starch**. In green algae (*e.g., Spirogyra, Ulothrix*), the chloroplasts possess special starch storing structures called **pyrenoids**.

Thylakoids (Menke, 1961). They are membrane lined flattened sacs which run throughout the stroma or matrix of the chloroplast. Since, they take part in photosynthesis, they are also called photosynthetic thylakoids. Thylakoids are thus the **structural elements** of the chloroplast. They generally run parallel but may show interconnections. Thylakoids may also be attached to the inner membrane of chloroplast envelope.

In the chloroplasts of higher plants, thylakoids are stacked at places to form grana. 40–60 grana may occur in a chloroplast. Each granum has 2–100 thylakoids. Grana are absent in algal chloroplasts. The latter are, therefore, **agranal**.

Because of the presence of grana, thylakoids are differentiated into two— granal thylakoids and stroma or intergranal thylakoids. A granum is attached to only a few stroma or

nongranal thylakoids, though it is made up of upto 100 thylakoids. It is, therefore, believed that the thylakoids get folded and bifurcated in the region of grana.

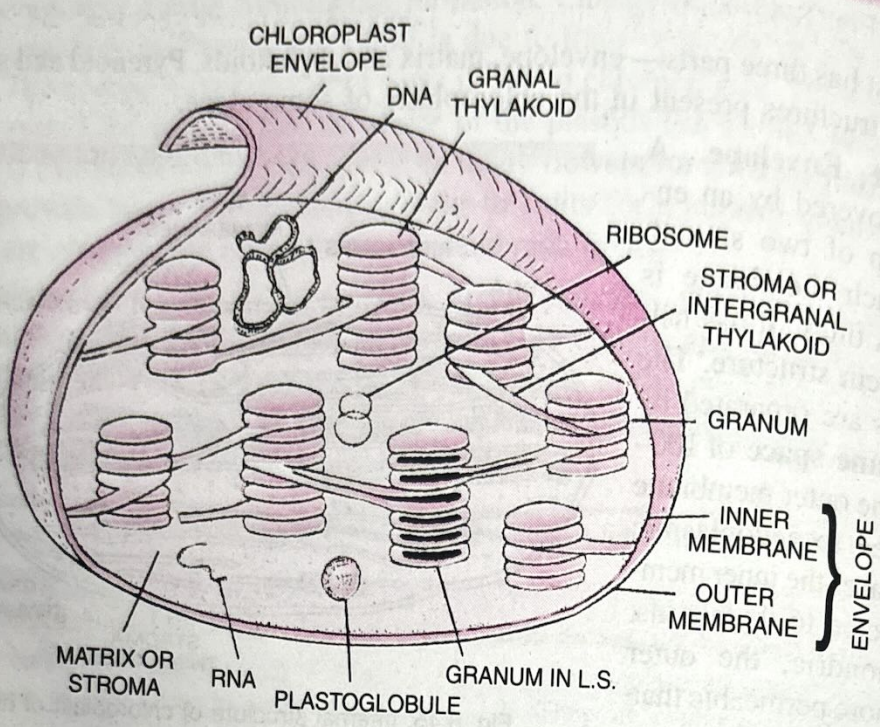

Fig. 8.46. Schematic 3-dimensional structural diagram of a chloroplast.

Thylakoid membranes possess photosynthetic pigments and coupling factors. Coupling factors are involved in ATP synthesis. Photosynthetic pigments include chlorophyll *a*, chlorophyll *b*, carotenes and xanthophylls. They occur in specific groups called photosystems (previously quantasomes). There are two photosystems, I and II. Photosystem II occurs in appressed parts of granal thylakoids while photosystem I is found in stromal thylakoids and nonappressed parts of granal thylakoids.

Functions

1. **Photosynthesis.** Chloroplasts are the centres of photosynthesis or formation of organic compounds from inorganic raw materials. The organic substances, thus synthesised, not only provide body building material to autotrophic plants themselves but also to all heterotrophic plants as well as animals.

2. **Energy Transduction.** Chloroplasts are able to trap sun energy and change it into chemical energy. The chemical energy is used by all living organisms to perform their life activities.

3. **Consumption of Carbon Dioxide.** Chloroplasts pick up carbon dioxide and use the same in photosynthesis. This keeps the percentage of this gas balanced in the atmosphere as carbon dioxide is being constantly added to it through combustion and respiration.

4. **Liberation of Oxygen.** Chloroplasts liberate oxygen which is passed into the atmosphere. This keeps the balance of oxygen constant in the atmosphere, as oxygen is being consumed in respiration and combustion.

5. **Storage of Starch.** They store starch either temporarily (in higher plants) or permanently (in several algae).

6. **Photosensitivity.** Chloroplasts of some algae provide photosensitivity because of the presence of stigma or eye spot.

7. **Reducing Power.** The reducing power produced during light reaction (NADPH) is used in the reduction of nitrate and synthesis of amino acids.

8. **Synthesis of Fatty Acids.** Murphy and Leech (1978) have reported the synthesis of fatty acids in Spinach chloroplasts.

9. **Storage of Lipids.** Chloroplasts store fat in the form of plastoglobuli.

10. **Formation of Chromoplasts.** They can be changed into the chromoplasts to provide colour to many flowers and fruits for attracting animals.

Autonomy

Though chloroplasts are under the overall control of the nucleus of the cell, they possess a great degree of functional autonomy : (i) A chloroplast has its own DNA. The DNA is naked. It can show both replication and transcription (or produce RNA). (iii) The plastid manufactures some of its own proteins, enzymes and other biochemicals because of the presence of 70 S ribosomes which can help translate the coded information contained in mRNAs transcribed over chloroplast DNA. (iii) New chloroplasts arise either from division of pre-existing ones or the division of their precursors known as proplastids.

Similarities and dissimilarities between Mitochondria and Chloroplasts

Similarities

(1) Presence of double membrane envelope. (2) Formation of involutions from the inner membrane. (3) Both are semi-autonomous. (4) The organelles possess their own DNA, RNA and 70s ribosomes to have sufficient functional independence from the cellular machinery. cpt DNA is bigger than mt DNA. However, genetic information contained in these DNAs is limited. (5) DNA is naked in both. (6) They are formed by the division of pre-existing organelles. (7) They take part in energy transduction. (8) The organelles produce ATP. (9) Both of them can form fatty acids as well as amino acids. (10) Both occcur in eukaryotes and are absent in prokaryotes. (11) They are believed to be procaryotic symbionts.

Dissimilarities

Mitochondria	*Chloroplasts*
1. They are colourless cell organelles.	1. Chloroplasts are green organelles.
2. Mitochondria are found in all types of aerobic cells, both plants and animals.	2. They are restricted to only some protists and exposed cells of plants.
3. They are generally cylindrical in outline.	3. Chloroplasts are generally disc-shaped.
4. Their inner membrane is thrown up into folds called cristae.	4. The inner membrane gives rise to flattened sacs called thylakoids.
5. Cristae remain in contact with inner membrane.	5. Thylakoids usually break connection with the inner membrane.
6. Cristae do not form grana.	6. At places thylakoids produce grana.
7. Pigments do not occur in mitochondria.	7. The membranes of thylakoids possess chloroplylls and carotenoids.
8. Inner membrane and its cristae possess a large number of elementary particles for ATP synthesis.	8. ATP synthesis is carried out by coupling factors present only on the thylakoids.
9. Mitochondria do not take part in the conversion of light energy into chemical energy.	9. Chloroplasts are the centres of conversion of solar energy into chemical energy.

10. They liberate energy by breaking down of organic food.
11. Organic food is broken down to produce carbon dioxide and water.
12. Mitochondria consume oxygen.

10. They store energy by building up organic food.
11. Carbon dioxide and water are used as raw materials for synthesis of organic food in the process of photosynthesis.
12. Chloroplasts liberate oxygen.

Sphaerosomes or Oleosomes

Sphaerosomes (= spherosomes) *are small cell organelles bounded by single membrane which take part in storage and synthesis of lipid.* They were discovered by Perner in 1953. Sphaerosomes are small spherical and refractile vesicles which are 0.5–1.0 μm in diameter. They arise from endoplasmic reticulum (Harwood, 1997) and are surrounded by a single but **half unit membrane** with phospholipid monolayer having polar heads towards the cytosol and hydorphobic tails towards the inner side. The membrane is stabilised by proteins called **oleosins** (Buchanan *et al*, 2000). 98% of a sphaerosome is lipid. Proteins constitute the remaining 2%. Some proteins are probably enzymatic and take part in the synthesis of lipids. Because of the presence of lipids, sphaerosomes can be seen under light microscope after staining the cells with Sudan dyes and osmium tetraoxide. Sphaerosomes occur abundantly in the endosperm cells of oil seeds. Sphaerosomes of some tissues (*e.g.*, tobacco endosperm, maize root tip) contain hydrolytic enzymes. Therefore, they are considered to have lysosomic activity.

MICROBODIES (Rhodin, 1954)

They are small cell organelles bounded by single membrane which absorb molecular oxygen and take part in oxidations other than those involved in respiration. Microbodies are of two types— peroxisomes and glyoxysomes.

(i) **Peroxisomes.** *They are microbodies which contain enzymes for peroxide biosynthesis.* Peroxisomes were discovered by De Duve *et al* (1965) with the help of fractionation technique. The term was coined by De Duve in 1969. Peroxisomes are found in both plant and animal cells, generally in close association with endoplasmic reticulum, mitochondria and chloroplasts. Despite absence of DNA, peroxisomes are believed to be able to replicate like mitochondria and plastids (Waterham and Craig, 1997). They are believed to vestige of an ancient organelle present in protoeucaryotes which performed all oxidation reactions prior to evolution of mitochondria. They contain special docking proteins called **peroxins** for obtaining materials from cytosol and endoplasmic reticulum. Peroxisomes occur in all eucaryotic cells. They are quite abundant in liver and kidney cells. A photosynthetic cell may have 70–100 peroxisomes. Peroxisomes are believed to develop from endoplasmic reticulum. Their size and shape are variable. Commonly the peroxisomes have a diameter of 0.5–1.0 μm. They are covered over by a single membrane. The interior contains a matrix which may be granular or have fibrils arranged variously. In some cases the matrix has a central dense, crystalline or fibrous core which is called **nucleoid**.

The peroxisomes contain oxidative enzymes like urate oxidase, D-amino acid oxidase, α-hydroxy acid oxidase and β-hydroxy acid oxidase. Molecular oxygen is required. The reactions produce hydrogen peroxide which is immediately metabolised by another enzyme called catalase.

(a) In animal cells, peroxisomes metabolise in number of toxic substances like nitrite, phenols, formaldehyde, formic acid, methanol, ethanol etc. 25% of alcohol consumed by a person is detoxified inside liver cells.

(b) Unusual substances or **xenobiotics** (*e.g.*, D-aminoacids, alkanes) which cannot be metabolised by normal enzymes are broken down inside peroxisomes.

(c) Urate produced during catabolism of nucleic acids and some proteins is changed into allontoin inside peroxisomes.

(d) Long chain (*e.g.*, prostaglandins) and branched chain fatty acids are initially broken down by peroxisomes.

(e) In root nodules, they convert fixed nitrogen in ureids for transport (Atkins, 1991).

(f) Plant peroxisomes found in photosynthetic cells, perform **photorespiration**. For this, they are associated with chloroplasts and mitochondria. Peroxisomes pick up glycolate from chloroplasts. The same is oxidised with the help of oxygen to produce glyoxylate. Hydrogen peroxide is formed as byproduct. Glyoxylate is changed to amino acid glycine. The glycine condenses to produce amino acid serine and carbon dioxide.

(ii) **Glyoxysomes** (= Glyoxisomes; Briedenbach, 1967, Fig. 8.47). *Glyoxysomes are microbodies which contain enzymes for β-oxidation of fatty acids and glyoxylate pathway.* They are considered to be special peroxisomes. The microbodies appear transiently in germinating oil seeds and the cells of some fungi till the stored fat is consumed. Like other microbodies, glyoxysomes have a single covering membrane and an enzyme rich matrix with a crystalloid core. β-oxidation of fatty acids produces acetyl CoA. The latter is metabolised in glyoxylate cycle to produce carbohydrates. After completion of their function, glyoxysomes are believed to be changed into peroxisomes. They reappear in senescent plant tissues for degradation of lipids and mobilisation of degradation products.

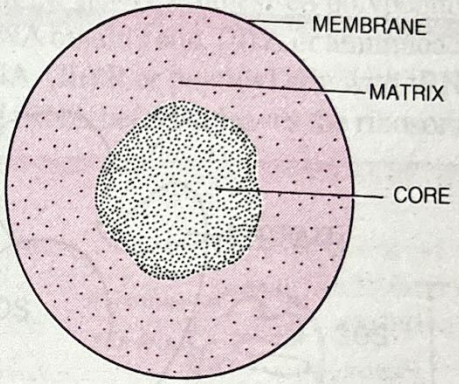

Fig. 8.47. Structure of glyoxysome.

RIBOSOMES (Palade Particles)

Ribosomes were discovered by Robinson and Brown (1953) in plant cells and by Palade (1955) in animal cells. Palade (1955) also coined the term of ribosome. A large number of ribosomes occur in a cell. For example, a single cell of bacterium *Escherichia coli* contains 20000–30000 ribosomes. Their number in eucaryotic cells is several times more. *Ribosomes are naked ribonucleoprotein protoplasmic particles (RNP) with a length of 200–340 Å and diameter of 170–240Å which function as the sites for protein or polypeptide synthesis.* Ribosomes are popularly known as **protein factories**. They are subspherical in outline. A covering membrane is absent. Each ribosome consists of two unequal subunits, larger dome shaped and smaller oblate-ellipsoid. The large subunit has a protuberance, a ridge and a stalk. The smaller subunit possesses a platform, cleft, head and base. It is about half the size of larger subunit. The smaller subunit fits over the larger one at one end like a cap (Fig. 8.49). Mg^{2+} is required for binding the two subunits (Below 0.0001 M Mg^{2+} the two subunits dissociate while above this strength the ribosomes can come together to form dimers Fig. 8.48).

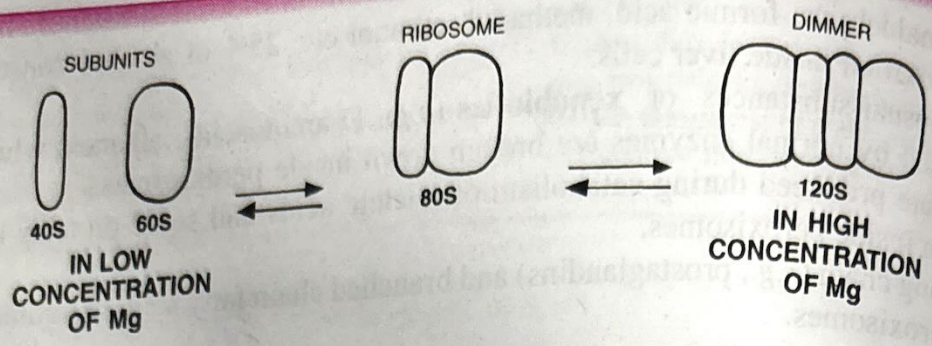

Fig. 8.48. Diagram to illustrate the effect of Mg concentration on ribosome.

Ribosomes may occur singly as **monosomes** or in rosettes and helical groups called **polyribosomes** (Rich, 1963) or **polysomes** (Gk. *poly*– many, *soma*– body). The different ribosomes of a polyribosome are connected with a 10–20 Å thick strand of messenger or mRNA (Fig. 8.50) The maintenance of polyribosome requires energy. Polyribosomes are formed during periods of active protein synthesis when a number of copies of the same polypeptide are required.

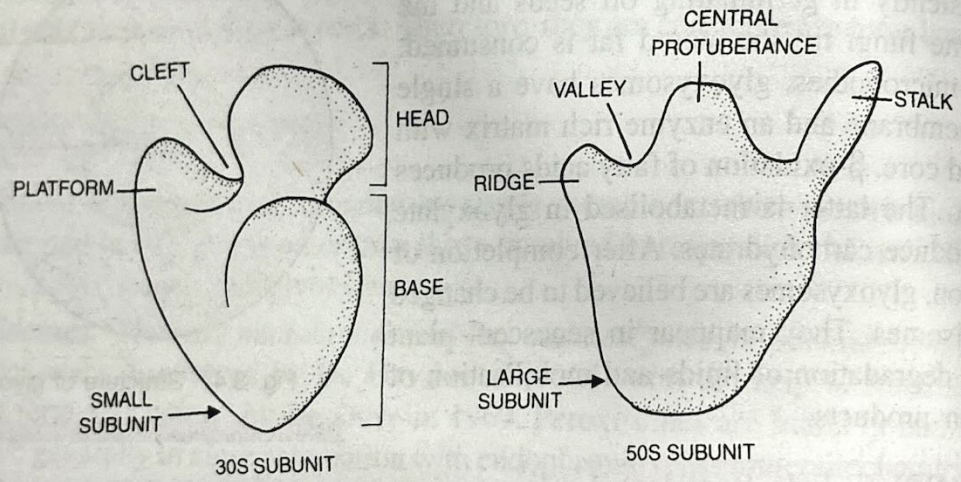

Fig. 8.49. Parts of ribosome.

Ribosomes occur in all living cells with the exception of mammalian erythrocytes or red blood corpuscles. Depending upon the place of their occurrence, ribosomes are of two types, cytoplasmic and organelle. The organelle ribosomes are found in plastids (plastidoribosomes) and mitochondria (mitoribosomes). The cytoplasmic ribosomes (cytoribosomes) may remain free in the cytoplasmic matrix or attached to the cytosolic surface of endoplasmic reticulum with the help of a special ribophorin or SRP protein. Attachment occurs through larger or 60 S subunits. Different types of ribosomes may produce different types of proteins, *e.g.*, structural proteins from free cytoplasmic ribosomes and globular proteins from ribosomes bound to ER. The bound ribosomes generally transfer their proteins to cisternae of the endoplasmic reticulum for transport to other parts both inside and outside the cell. They are also sent to intracellular organelles like nucleus, mitochondria and chloroplasts. Newly synthesised proteins are assisted in their folding and transport by specific proteins called **chaperones**.

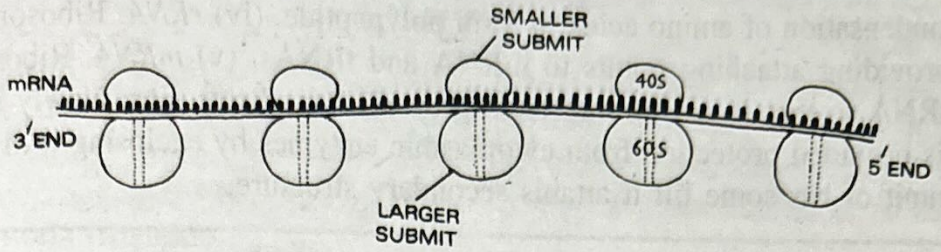

Fig. 8.50. Polyribosome.

The size of the ribosomes is determined by sedimentation coefficient in the centrifuge. It is measured as Svedberg unit called S ($S = 1 \times 10^{-13}$ sec). The cytoplasmic ribosomes of eucaryotes are 80 S. They have a size of 300–340 Å× 200–240 Å and mass of 4.0–4.5 million daltons. The cytoplasmic ribosomes of procaryotes (PPLO, bacteria, blue-green algae) are 70 S. The size is 200–290 Å × 170–210 Å and mass is 2.7–3.0 million daltons (Fig. 8.51). The organelle ribosomes are also 70 S but in mammalian mitochondria they have sedimentation coefficient of 55 S. The two subunits of **80 S ribosomes** are 60S and 40S while **70S ribosomes** have 50S and 30 S subunits. A tunnel occurs between the two subunits for passage of mRNA. The larger subunit has a groove for pushing out the newly synthesised polypeptide. A ribosome has four sites for specific attachments. (i) mRNA binding site. (ii) A or amminoacyl **site** for binding to newly arrived aminoacid carrying tRNA. (iii) **P** or peptidyl **site** with tRNA carrying growing polypeptide. (iv) **E** or exit **site** for freed tRNA before it leaves the ribosome.

80S ribosomes are synthesised inside the nucleolus. Proteins come from cytoplasm. 5S RNA is synthesised separately while others are formed by the nucleolus. 80S ribosomes do not become functional inside the nucleolus. Their subunits come out of the nucleus and become operational in cytoplasm. 70S ribosomes of procaryotes are formed in the cytoplasm while those of semi-autonomous cell organelles are formed in their matrix.

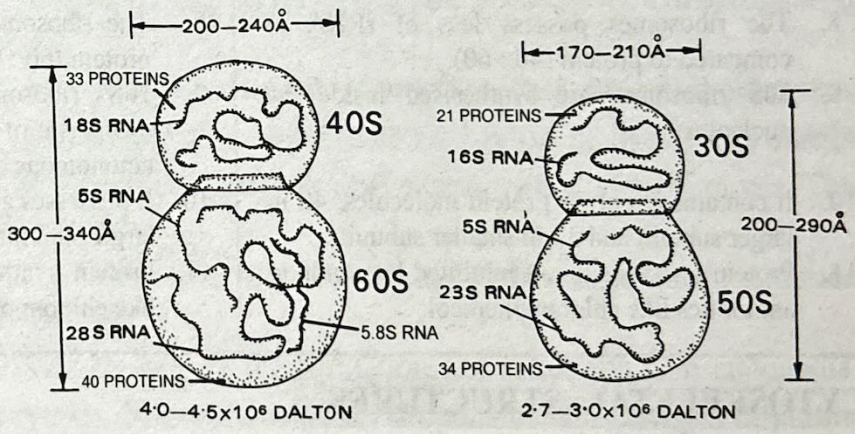

Fig. 8.51. 80S and 70S Ribosomes and their components.

Chemically a ribosome is made of two parts, proteins and rRNA. The ribosomes of liver cells may also contain lipids to the extent of 5–10%. Usually more rRNA is present in 70S ribosomes as compared to protein (60–65 : 35–40) while the reverse is true for 80S ribosomes (40–44 : 56–60). 40S subunit of 80S ribosome contains 33 protein molecules and a single 18S rRNA. 30S subunit of 70S ribosome possesses 21 protein molecules and 16S rRNA. 60S subunit of 80S ribosome has 40 protein molecules and three types of rRNAs— 28S, 5.8S and 5S. 50S subunit of 70S ribosome contains 34 protein molecules and two types of rRNAs— 23S and 5S. Proteins are both structural and enzymatic.

Functions. (i) *Protein Factories*. Ribosomes are sites for polypeptide or protein synthesis. (ii) *Free and Attached Ribosomes*. Free ribosomes synthesise structural and enzymatic proteins for use inside the cell. The attached ribosomes synthesise proteins for transport.

(iii) *Enzymes and Factors.* Ribosomes provide enzymes (*e.g.*, Peptidyl transferase) and factors for condensation of amino acids to form polypeptide. (iv) *rRNA.* Ribosome contains rRNAs for providing attaching points to mRNA and tRNAs. (v) *mRNA.* Ribosome has a tunnel for mRNA so that it can be translated properly. (vi) *Protection.* Newly synthesised polypeptide is provided protection from cytoplasmic enzymes by enclosing it in the groove of larger subunit of ribosome till it attains secondary structure.

Differences between 80S and 70S Ribosomes

80S Ribosomes	*70S Ribosomes*
1. They occur only in eucaryotic cells.	1. 70S ribosomes are found both in procaryotes and eucaryotes.
2. They occur inside the cytoplasm of eukaryotes either freely or attached to ER.	2. The ribosomes are found freely inside the cytoplasm of prokaryotes and matrix of plastids and mitochondria of eukaryotes.
3. The ribosomes are larger in size with a length of (300—340 Å) and breadth (200—240 Å).	3. They are comparatively smaller with a length of (200—290 Å) and a diameter of (170—210 Å).
4. The sedimentation co-efficient is 80.	4. The sedimentation coefficient is 70.
5. They are comparatively heavier, 4.0—4.5 million daltons.	5. 70S ribosomes are comparatively lighter, 2.7—3.0 million daltons.
6. The two subunits are 40S and 60S.	6. The two subunits are 30S and 50S.
7. The rRNAs of 80S ribosomes are 28S + 5.8S + 5S in larger subunit and 18S in smaller subunit.	7. The rRNAs of 70S ribosomes are 23S + 5S (larger subunit) and 16S (smaller subunit).
8. The ribosomes possess less of rRNA as compared to protein (40 : 60).	8. The ribosomes contain more of rRNA than protein (60 : 40).
9. 80S ribosomes are synthesised inside the nucleolus.	9. 70S ribosomes are synthesised in the cytoplasm of procaryotes and matrix of semi-autonomous cell organelles.
10. It contains about 73 protein molecules, 40 in larger subunit and 33 in smaller subunit.	10. It possesses about 55 protein molecules, 34 in larger subunit and 21 in smaller subunit.
11. Protein synthesis is not inhibited by common antibiotics like chloramphenicol	11. Protein synthesis is inhibited by antibiotics like chloramphenicol.

CYTOSKELETAL STRUCTURES

They are extremely minute, fibrous and tubular structures which form the structural frame-work inside the cell. Cytoskeletal structures occur only in eucaryotic cells. They were discovered with the help of fluorescence microscopy. Cytoskeletal structures maintain shape of the cell and its extensions, regulate oreintation and distribution of cell organelles, intra cellular transport and movement of cells. They are of three types :– microfilaments, intermediate filaments and microtubules.

(i) **Microfilaments** (Paleviz *et al*, 1974). They are ultramicroscopic long, narrow cylindrical rods or protein filaments which occur in eukaryotic plant and animal cells. Microfilaments are made up of **actin** (also present in muscle myofibrils) constituting 10–15% of total cell protein. They are 6–8 nm in thickness and show periodic beaded appearance due to close helical arrangement of otherwise globular actin molecules (Fig. 8.52).

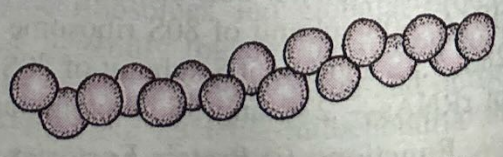

Fig. 8.52. Helical arrangement of actin molecules in a microfilament.

Microfilaments often associate to form hexagonal **bundles**. They may also occur in parallel bundles or loose network. Microfilaments generally lie at sol-gel interphase as well as below plasma membrane. Microfilaments are also connected with spindle fibres, endoplasmic reticulum, chloroplast, etc. In some primitive organisms spindle apparatus seems to be made of microfilaments. During mitosis of animal cells, they have been found associated with cleavage furrows. Stabilisation of membrane proteins has recently been found to be related to their association with microfilaments.

Microfilments are conctractile. Association with myosin protein seems to be essential for contraction of microfilaments. Myofibrils of muscle fibres also contain microfilaments. Microfilaments form the contractile machinery of the cell which aids in motility, like formation and retraction of pseudopodia and plasma membrane undulations, formation of microvilli, endocytosis, cytoplasmic streaming and movement of other cell organelles.

Microvilli are thread-like protoplasmic projections which are formed on the free surface of absorptive cells like those of intestine. Each microvillus is covered by an extension of plasmalemma. Its core contains a number of microfilaments. The microfilaments are attached to the plasmalemma extension.

Functions

1. *Cytoplasmic Streaming*. Cyclosis is caused by the activity of microfilaments.
2. *Membrane Proteins*. They help in stabilisation of membrane proteins.
3. *Support.* They are components of cytoskeleton of cell that is required to support otherwise fluid cytoplasmic matrix.
4. *Change in Form.* Microfilaments play an important part in change of cell form during development and differentiation.
5. *Myofibrils*. Myofibrils are contractile elements of muscles. They have microfilaments.
6. *Microvilli*. Microvilli are maintained through the support provided by microfilaments.
7. *Movement of Microvilli.* Microvilli show microfilament mediated movements. This aids in quicker absorption of materials.
8. *Membrane Undulations*. Fibroblasts are able to move due to plasma membrane undulations caused by microfilaments.
9. *Pseudopodia*. Microfilaments help in the formation and retraction of pseudopodia.
10. *Endocytosis* and *Exocytosis.* Microfilaments are responsible for changes in plasma membrane during endocytosis and exocytosis.
11. *Spindle Apparatus*. The spindle apparatus of few organisms is composed of microfilaments.
12. *Cleavage*. Microfilaments are associated with cleavage furrow at the time of cytokinesis.
13. *Movement of Cell Components.* Pigment granules, chloroplasts and other cell organelles are able to change their position inside the cytosol by means of microfilaments.

(ii) **Intermediate Filaments** (Fig. 8.53). They are nearly solid unbranched filaments of about 10nm thickness which are formed by a variety of proteins and often form a network. Intermediate filaments are of four types: (a) **Keratin Filaments.** They form tonofibrils of desmosomes and keratin of skin. (b) **Neurofilaments.** Filaments form a lattice with bundles of microtubules in axons and dendrons of nerve cells. (c) **Glial Filaments.** They are intermediate filaments found in astrocytes. (d) **Heterogeneous Filaments.** They are intermediate filaments found in muscles (Z-lines, M-lines), as basket around

nucleus and connected to centriole, etc. Heterogeneous filaments are of three types— synemin filaments, vimentin filaments and desmin filaments. Intermediate filaments do not occur in unicellular eukaryotes. They evolved in multicellular eukaryotes. The filaments are cross linked with one another as well as various cellular structures including plasmalemma by means of IF associated proteins, *e.g.*, plakins, plectins.

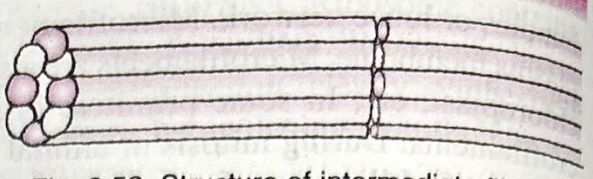

Fig. 8.53. Structure of intermediate filament.

Functions

1. **Nuclear Matrix.** It is mainly formed of intermediate filaments.
2. **Support to Membranes.** IF provide support to all biomembranes including plasmalemma and nuclear membranes.
3. **Cytoplasm.** IFs constitute scaffold or supporting array for cytoplasm.
4. **Muscles.** A lattice of desmin filaments not only surrounds each Z-disc but is also connected to sarcolemma. This provides support to contractile units or sarcomeres.
5. **Desmosomes.** Desmosomes are supported by intermediate filaments called **tonofibrils.**
6. **Epithelial Tissues.** IFs maintain the integrity of epithelial tissues.
7. **Keratin.** Keratin deposited in the skin cells provides protection against abrasions.
8. **Nervous Tissue.** Intermediate filaments provide mechanical strength to axons and dendrons of nerve cells (as neurofilaments) and astrocytes (as glial filaments).

(iii) **Microtubules** (De Robertis and Franchi, 1953). Microtubules are unbranched hollow submicroscopic tubules of protein tubulin which develop on specific nucleating regions and can undergo quick growth or dissolution at their ends by assembly or disassembly of monomers. Colchicine prevents assembly of microtubules. It, therefore, prevents spindle formation during cell division. With the exception of Slime Moulds and Amoebae, microtubules occur widely in eukaryotic cells. They are present in the cytoplasm as well as in specialized structures like centrioles, basal bodies, cilia or flagella, sensory hair, equatorial ring of thrombocytes, spindle apparatus, chromosome fibres, nerve processes, sperm tails, axostyle of parasitic flagellates, fibre system of *Stentor*, cyto-pharyngeal basket of *Nassula*, etc. Microtubules are of indefinite length. Their diameter is 25 nm with a core of 15 nm and wall of 5 nm thickness. The wall is formed of 13 laterally associated and helically arranged longitudinal strands called protofilaments. These strands are made of alternate spirals (Fig. 8.54) of two related proteins called α– and β-**tubulins**. The surface of a microtubule may also possess **arms**, lateral projections of 100–400 Å length and 20–50 Å thickness. They may help in forming cross-bridges among themselves and various types of cellular structures like plasmalemma, endoplasmic reticulum, nuclear envelope and other organelles. The arms seem to be involved in movement of cytosol in the area of microtubules.

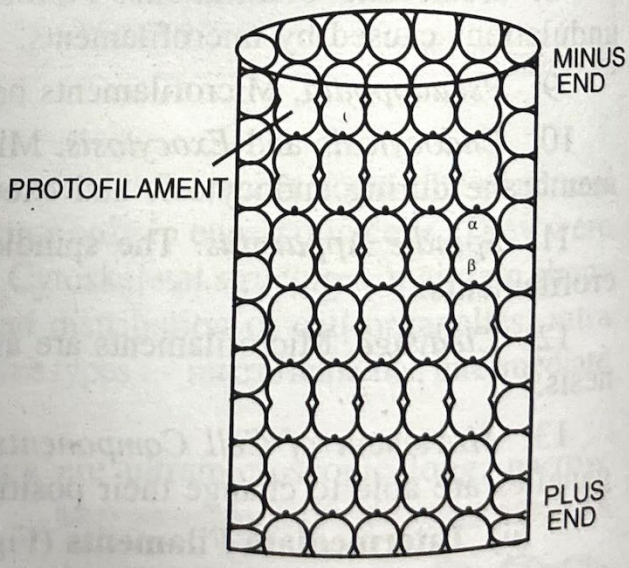

Fig. 8.54. Arrangement of tubulin molecules in a microtubule.

Functions

1. **Structural Components.** Microtubules are constituents of spindle fibres, chromosome fibres, centrioles, basal bodies, flagella and cilia.
2. **Cytoskeleton.** Microtubules function as cytoskeleton. They provide rigidity and shape to some cell parts like pseudopodia of some protistans and axons of nerve cells.
3. **Intracellular Transport.** They are believed to function either as microcirculatory system or directing movement of vesicles to a particular part with the help of their arms.
4. **Orientation of Microfibrils.** In plant cells the microtubules control orientation of cellulose microfibrils of the wall.
5. **Shape.** Distribution of microtubules control the shape of wall-less cells and nuclei.
6. **Nuclear Movements.** They help in the movement of nuclei during division.
7. **Movement of Chromosomes.** As chromosome or tractile fibrils, the microtubules take part in the anaphasic movement of chromosomes.
8. **Cell Plate.** Place of future cell plate formation has been found to be determined by a microtubular band.
9. **Pushing of Food.** In protistans, microtubules help in driving the food in the gullet.
10. **Cell Differentiation.** They are believed to play a vital role during differentiation.
11. **Cell Polarity.** Distribution of microtubules determines cell polarity.
12. **Movements of Cilia and Flagella.** Being capable of sliding past one another, microtubules help in the movement of flagella and cilia.
13. **Cell Movements.** Alongwith microfilaments they take part in cell movements.

Differences between Microfilaments and Microtubules

Microfilaments	*Microtubules*
1. They are contractile.	1. They are non-contractile though change in length can occur through assembly and disassembly of constituent proteins.
2. They do not possess longitudinal subunits.	2. A microtubule contains 13 protofilaments.
3. Microfilaments are solid structures.	3. They are hollow tubules.
4. Microfilaments are made up of actin protein.	4. Microtubules are formed of α and β-tubulin.
5. The diameter of a microfilament is 6 nm.	5. The diameter of a microtubule is 25 nm.
6. They occur below cell membrane and at the interphase of plasmagel-plasmasol.	6. Microtubules occur in centrioles, basal bodies, cilia/flagella, astral rays, spindle fibre.
7. Microfilaments are believed to cause cytoplasmic streaming.	7. Microtubules cause microcirculation by directing vesicles to particular direction.
8. They take part in endoytosis.	8. Microtubules have no role in endocytosis but direct endosomes in particular direction.

FLAGELLA AND CILIA

They are fine hair like movable protoplasmic processes of the cells which are capable of producing a current in the fluid medium for locomotion and passage of substances. Flagella are longer (100–200 μm) but fewer. Only 1–4 flagella occur per cell, *e.g.*, many protists, motile algae, spermatozoa of animals, bryophytes and pteridophytes, choanocytes of sponges, gastrodermal cells of coelenterates, zoospores and gametes of thallophytes. Cilia are smaller (5–20 μm) but are numerous. They occur in group ciliata of protista, flame cells of worms, larval bodies of many invertebrates, epithelium of respiratory tract, renal tubules,

oviducal funnel, etc. Cilia present on the tracheal and bronchial epithelial cells are specialised to send back dust particles into the pharynx so that the lungs remain unharmed. However, cigarette smoking reduces/stops ciliary activity so that air borne dust particles pass into the lungs of smokers causing irrepairable harm.

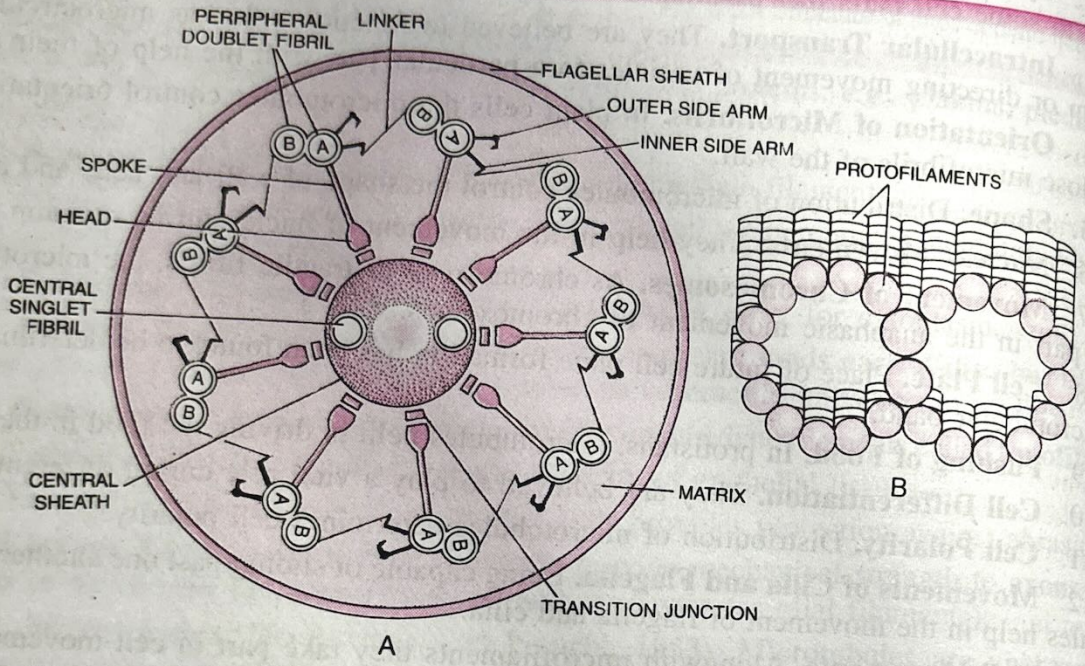

Fig. 8.55. A, ultrastructure of flagellum in cross-section. B, doublet fibril without arms.

Both cilia and flagella are structurally similar and possess similar parts— basal body, rootlets, basal plate and shaft (Fig. 8.55).

(i) *Basal Body or Kinetosome*. It is also called **basal granule** or **blepharoplast.** Basal body occurs embedded in the outer part of the cytoplasm below the plasma membrane. It is like a microcylinder which has a structure similar to a centriole with nine triplet fibrils present on the periphery without a central fibril, though a hub of protein is present here. Only subfibre A is complete (having 13 protofilaments) while subfibres B and C are incomplete as they share some of their protofilaments.

(ii) *Rootlets*. They are striated fibrillar outgrowths which develop from the outer lower part of the basal body and are meant for providing support to the basal body. The rootlets are made of bundles of microfilaments.

(iii) *Basal Plate*. It is an area of high density which lies above the basal body at the level of plasma membrane. In the region of basal plate, one sub-fibre of each peripheral fibril disappears. The central fibrils develop in this area.

(iv) *Shaft*. It is the hair-like projecting part of flagellum or cilium. The length is 5–20 μm in case of cilium and 100–200 μm in case of flagellum. The shaft is covered on the outside by a sheath which is the extension of plasma membrane. In **whiplash flagellum**, the sheath is smooth. In **tinsel flagellum**, the sheath contains a number of thick hairy outgrowths called **flimmers**. Internally, it contains a semifluid matrix having an **axoneme** of 9 peripheral doublet fibrils and 2 central singlet fibrils (Fig. 8.55). This arrangement is called 9 + 2 or 11-stranded. However 9 + 1 (*e.g.*, flatworm) and 9 + 0 (*e.g.*, eel, Asian Horseshoe Crab) arrangements have also been observed. The two central singlet fibres are

covered by a proteinaceous central sheath. They are connected by a double bridge. Each peripheral fibril consists of two microtubules or sub-fibres B and A. The sub-fibre A is slightly narrower. It bears two bent arms, the outer one having a hook. They are about 15 nm long and made up of protein **dynein** with ATP-ase activity. Such activity is also present in central fibrils. Movement of flagella or cilia occurs due to sliding motion in which dynein arm establishes temporary connection with subtubule B of adjacent doublet fibre. The peripheral doublet fibrils as well as central singlet fibrils are made up of tubulin. Each sub-fibre or central singlet fibril contains thirteen protofilaments. The peripheral doublet fibrils are interconnected by A-B linkers of protein **nexin** between B-subfibre of one and inner side arm of A-subfibre of adjacent fibril. Each of their A sub-fibres sends a radial proteinaceous column to the centre. It is called **spoke**. The spokes are broader internally to form heads or knobs. Head is connected to central proteinaceous sheath through transition junction.

The cilia and flagella move by sliding of the doublet fibrils against one another. Energy is provided by ATP. Flagella perform independent undulatory movements while cilia show rowing type of sweeping motion either simultaneously (isochronic or synchronous) or one after the other (metachronic). In a flagellum, several symmetrical undulatory waves pass from base to the tip. This pushes the cell along. Undulations passing from tip to base pull the cell through water. In tinsel flagellum having a number of flimmers, the undulatory wave moving down from base to tip also pulls the cell along instead of pushing it. There is always a **power stroke** and a **recovery** or **return stroke** (Fig. 8.57). The power stroke is able to move the fluid with a jerk in the direction of the stroke. The cell moves in the opposite direction, if it is motile. The recovery or return stroke is slow and without much force. Therefore, it does not cause much disturbance in the fluid medium. Rate of ciliary and flagellar movements is 10–40 strokes per second. Flagellate *Monas stigmatica* swims at the rate of 260 μm or 40 cell length/sec. It has the maximum speed per body length. *Paramoecium caudatum* has a speed of 1500 μm or 12 cell lengths/sec.

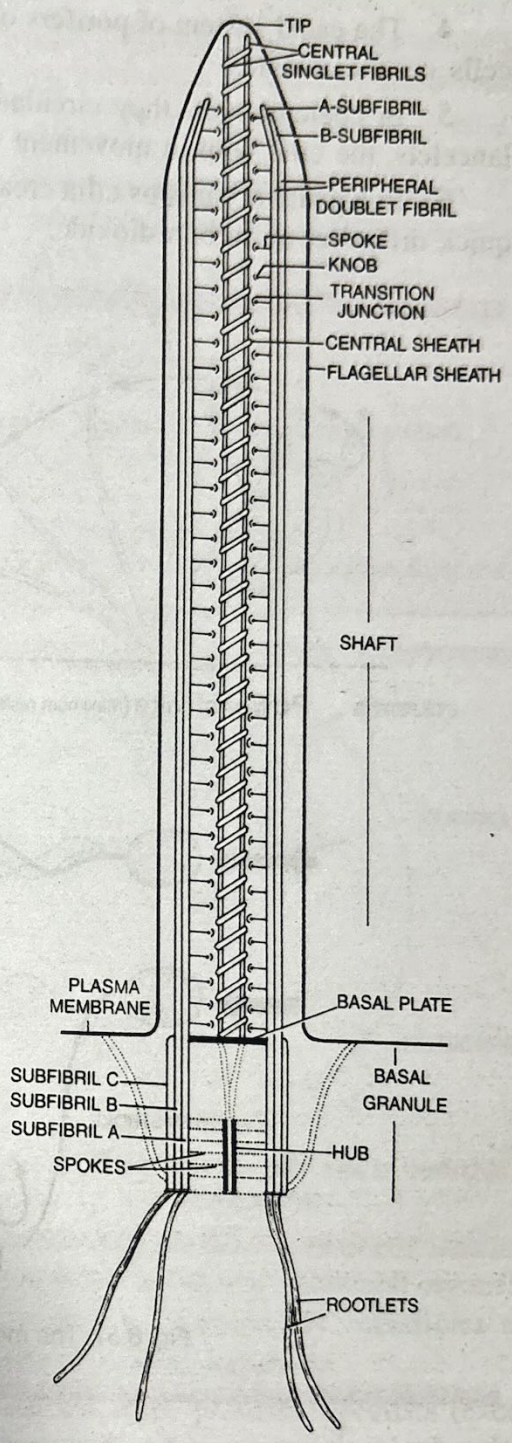

Fig. 8.56. L.S. of a flagellum (Diagrammatic).

Functions of Cilia and Flagella

1. They help in locomotion in flagellate and ciliated organisms.
2. They create current for obtaining food from aquatic medium.

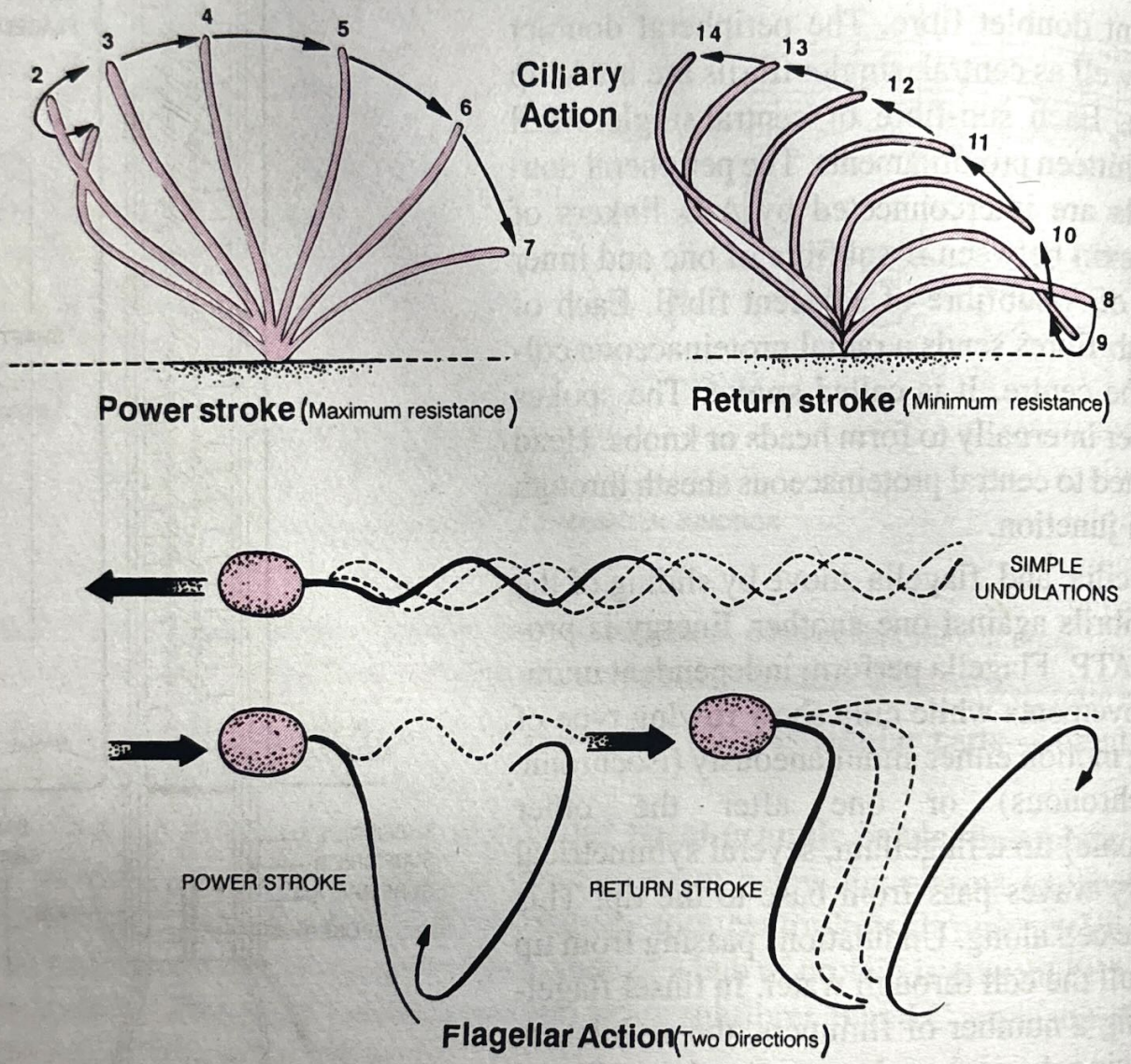

Fig. 8.57. The mode of movement in cilia and flagella.

7. In land animals the cilia of the respiratory tract help in eliminating dust particles in the incoming air.

8. Internal transport of several organs is performed by cilia, *e.g.*, passage of eggs in oviduct, passage of excretory substances in the kidneys, etc.

9. Being protoplasmic structures they can function as sensory organs.

10. Their tips secrete sticky substance to help in conjugation and fusion of gametes.

11. In certain protistans, cilia fuse to form undulating membrane.

12. Cilia and flagella show sensitivity to changes in light, temperature and contact.

13. Ciliated larvae take part in dispersal of the species.

Differences between Cilia and Flagella

Cilia	*Flagella*
1. The number of cilia per cell is usually very large (300—14000).	1. The number of flagella per cell is usually 1—4.
2. They are smaller (5—20 μm in length).	2. They are longer (100–200 μm in length).
3. Cilia usually occur throughout or major part of the surface of a cell.	3. Flagella are commonly found at one end of the cell.
4. They beat in a co-ordinated rhythm either simultaneously (isochronic or synchronous rhythm) or one after the other (metachronic rhythm).	4. The flagella beat independently.
5. Cilia produce a sweeping or pendular stroke.	5. The flagella produce undulatory motion.
6. Cilia help in locomotion, aeration, feeding circulation, etc.	6. Flagella help in locomotion.
7. Cilia may fuse to form undulating membrane.	7. Fusion of flagella is unknown.
8. Surface is smooth.	8. Surface may be smooth or possess flimmers.

CENTRIOLES

Centrioles are minute-submicroscopic microtubular subcylinders with a configuration of nine triplet fibrils and ability to form their own duplicates, astral poles and basal bodies, without having DNA and a membranous covering. They are approximately 0.3–0.5 μm in length and 0.15μm in diameter. They are visible under light microscope, but the details of centriole structure were revealed only under electron microscope. Usually two centrioles are found associated together but at right angles to each other (Fig. 8.58). The pair of centrioles is often called **diplosome**. Diplosome lies in a common specialized part of cytoplasm called **centrosphere** or **kinoplasm** (= cytocentrum). Centrosphere is devoid of any other cell organelle. It, however, contains a fine fibrous material. The complex, formed of centrioles and centrosphere, is called **centrosome** (Boveri, 1888) or central apparatus.

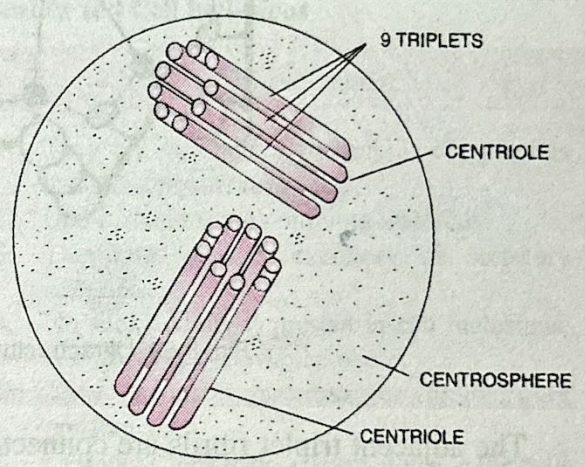

Fig. 8.58. Centrosome with pair of centroles (Diplosome).

Centrioles are found in almost all eukaryotic animal cells, protozoan protists (except some forms like *Amoeba*), some fungi and the cells of all those eukaryotic plants where flagellate structures are present in the life cycle (many green algae, bryophytes, pteridophytes and cycads). They are absent in angiosperms, higher gymnosperms, some algae and fungi.

Centrioles are capable of replication. Centriole replication is coordinated in animal cells with cell division. It occurs in S or G_2-phase. Prior to nuclear division, the two centrosomes separate and move to the opposite ends where spindle poles are to be established subsequently. Centriole replication also occurs at the time of formation of basal bodies of cilia and flagella.

A centriole possesses a whorl of nine peripheral fibrils. Fibrils are absent in the centre. The arrangement is, therefore, called 9 + 0. Fibrils run parallel to one another but at an angle of 40°. Each fibril is made up of three subfibres. Therefore, it is called **triplet** fibril. The

three subfibres are in reality microtubules joined together by their margins and, therefore, sharing the common walls made of 2–3 protofilaments. Each subfibre has a diameter of 25 nm. From outside to inside the three sub-fibres of a triplet fibril are named as C, B and A. Subfibre A is complete with 13 protofilaments while B and C subfibres are incomplete due to sharing of some microfilaments.

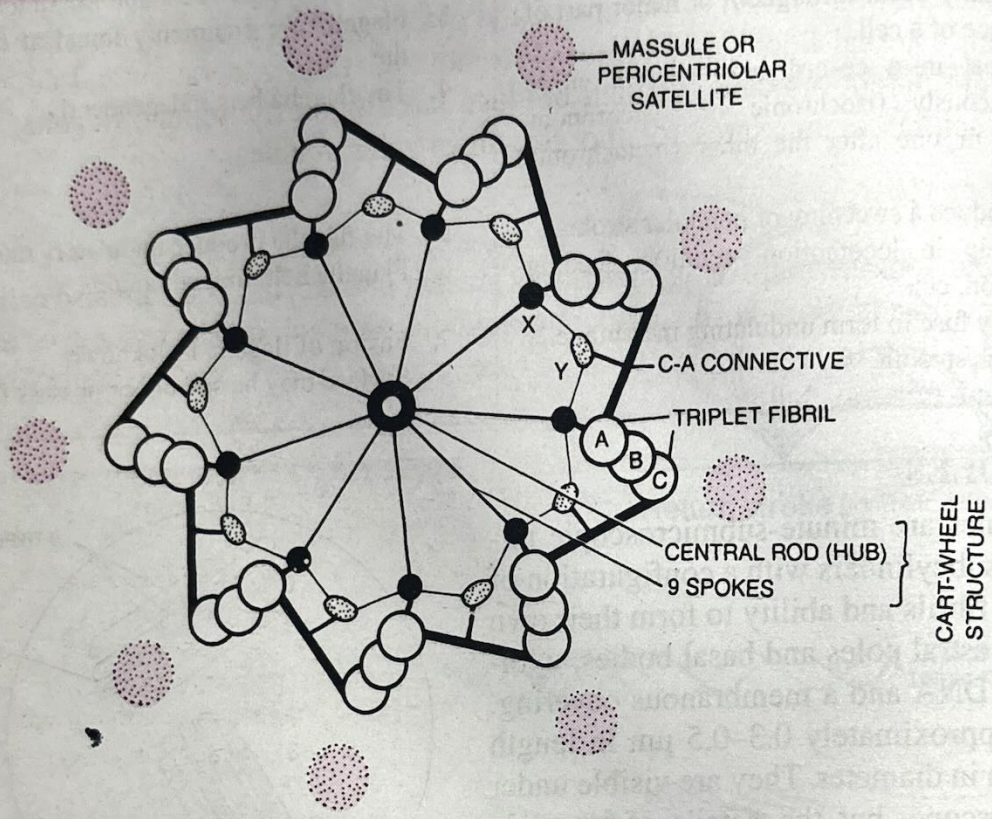

Fig. 8.59. Ultrastructure of centriole as seen in T.S.

The adjacent triplet fibrils are connected by C—A proteinaceous **linkers**. The centre of centriole possesses a rod-shaped proteinaceous mass known as **hub**. The hub has a diameter of 2.5 nm. From the hub, develops 9 proteinaceous strands towards the peripheral triplet fibrils. They are called spokes. Each spoke has a thickening called X before uniting with A sub-fibre. Another thickening known as Y is present nearby. It is attached both to X thickening as well as C—A linkers by connectives. Due to the presence of radial spokes and peripheral fibrils, the centriole gives a cart wheel appearance in T.S (Fig. 8.59).

On the outside of centriole are present dense, amorphous, protoplasmic plaques in one or more series. They are called **massules** or pericentriolar satellites. Their position is change able with the different states of the cell. Massules act as nucleating centres for the growth of microtubules during aster formation and production of more centrioles (during G_2 phase).

Functions

1. Though centrioles have not been found to contain DNA, yet they are capable of forming new centrioles with the help of massules which function as nucleating centres.
2. Centrioles help in cell division by forming microtubule-organising centres (MTOCs).
3. Out of the two centrioles in a spermatozoan, the distal one forms axial filament or tail.
4. Centrioles can be transformed into basal bodies.
5. Basal bodies formed from centrioles give rise to cilia and flagella.

Resemblances among Centrioles, Cilium and Flagellum

Centriole, cilium and flagellum resemble one another in their broad structure and function. (i) All of them are made up of microtubules. (ii) The three possess nine peripheral fibrils of microtubules. Fibril organisation is 9 + 0 in centrioles and 9 + 2 in case of cilia and flagella. (iii) Basal granule present at the base of a cilium or flagellum is derived from a centriole and resembles the same in structure. (iv) All the three are capable of movements. Centriole does so to a limited extent inside the cytoplasm. A cilium or flagellum produces a current in an external liquid medium for locomotion, feeding, aeration and circulation. (v) Centrioles are parent organelles which produce basal bodies, cilia and flagella. They have nucleating centres or massules for the growth of microtubules.

CELL INCLUSIONS

Cell inclusions are non-living substances present in the cells. They are also called ergastic bodies. They may be present in soluble or insoluble state and can be organic or inorganic in nature. The cell inclusions belong to three categories— reserve food, excretory or secretory products and mineral matter.

Differences between Cell Organelles and Cell Inclusions

Cell Organelles	*Cell Inclusions*
1. Cell organelles are components and sub-components of cell.	1. They are substances present in components and subcomponents of cell.
2. They are living structures.	2. Cell inclusions are nonliving materials.
3. Cell organelles develop from pre-existing organelles or precursors.	3. They are storage, excretory or secretory materials.
4. They are capable of growth.	4. No such activity is present in cell inclusions. Accretion may, however, occur.
5. Cell organelles perform metabolic activities.	5. They are raw materials or products of metabolism.
6. They are formed inside the cells.	6. Cell inclusions may be formed inside the cells or obtained from outside.
7. They are never passed outside the cells.	7. They get exported or expelled from cell.

1. **Reserve Food**. They are of four main types— starch, glycogen, fat droplets and aleurone grains.

(i) *Starch Grains*. They occur in plant cells. The grains are found in chloroplasts and amyloplasts. As such they are insoluble. The grains may occur singly when they are called simple. They are called compound starch grains when two or more of them occur in amyloplasts, *e.g.*, Rice, Oat.

Each starch grain has a central proteinaceous area called **hilum**. Starch is deposited around it in the form of layers. Depending upon the position of hilum, a starch grain may be concentric or eccentric. The starch grains (Fig. 10.4) are oval eccentric in potato, oval and concentric in gram or pea, rounded, flat and concentric in wheat and polyhedral with radiating lines in maize.

Experiment. Study of Starch Grain

Apparatus. Maize or wheat starch/potato slice, glass slide, dilute glycerine, cover slip, microscope, iodine (I-KI) solution.

Working. Crush a small piece of potato slice on a glass slide. Alternately place very small quantity of maize or wheat starch on a glass-slide by means of a needle. Pour a drop of dilute glycerine over the same. Cover the starchy liquid by means of a coverslip and examine under the miscroscope. Find that the slide contains a number of distinct grains having a hilum and layers of starch over the same. The starch grains are oval and eccentric in potato, rounded flat and concentric in wheat and polyhedral with radiating lines but concentric in maize. Introduce a small quantity of iodine solution from one side of cover-slip. The starch grains will soon turn dark blue.

(ii) *Glycogen Granules.* They are minute granules of storage carbohydrate which occur in animal cells, especially near the smooth endoplasmic reticulum inside the liver and muscle cells. The granules are flattened, circular or oval bodies which may get grouped to form rosette-shaped aggregates. They stain red with iodine.

(iii) *Fat Droplets.* They occur in both plant and animal cells. Animal cells specialized to store fat are called **adipocytes**. One to several droplets may occur in a cell. Usually the cytoplasm of adipocytes is pushed to the periphery and the nucleus lies on one side. In plants fat droplets or globules occur abundantly inside the seeds either in endosperm (*e.g.*, Castor, Coconut) or cotyledons (*e.g.*, Groundnut, Mustard).

(iv) *Aleurone Grains.* They represent the storage proteins which are generally insoluble and occur inside special leucoplasts called aleuroplasts. Depending upon their internal structure, aleurone grains are of four types— (a) amorphous (b) protein matrix containing a crystalloid, *e.g.*, outer aleurone layer of endosperm in wheat, maize, barley grains (c) protein matrix with globoid (d) protein matrix having both crystalloid and globoid inclusion, *e.g.*, endosperm cells of castor seeds. Crystalloid is crystal-like protein-carbohydrate body while globoid contains lipid and phytin.

2. **Excretory or Secretory Products**. They are of several types like mucus in several animal cells, essential oils, alkaloids, resins, gums, tannins, latex, etc. Two types of **pigment granules** occur in animals, **melanins** and **lipochromes**. They are produced by two different types of pigment producing **chromatophores**, melanophores and lipophores. Melanins are brownish or blackish granules. Lipochromes are orange, red or yellow in colour.

3. **Mineral Matter** (Crystals). It occurs as crystals or incrustations of silica, calcium carbonate, calcium sulphate and calcium oxalate. Silica is generally deposited on the outer side of epidermal cells in several plants especially grasses. Calcium carbonate is deposited in the form of a mass of crystals around a skeleton of cellulose. The product is called **cystolith**, *e.g.*, epidermal cells of *Momordica* and hypodermal leaf cells of Banyan. Calcium oxalate occurs in several forms— powdery mass called **crystal sand** (*e.g., Atropa*), star shaped aggregate of crystals called **sphaeraphide** (*e.g., Colocasia, Begonia, Chenopodium*), **prismatic crystals** (*e.g.*, dry scales of Onion) and needles called **raphides** (*e.g., Lemna, Eichhornia*).

IV. NUCLEUS

Nucleus (L. *nucleus*– kernel) *is a specialized double membrane bound protoplasmic body which contains all the genetic information for controlling cellular metabolism and transmission to the posterity.* A nucleus in the non-dividing or metabolic phase is called **interphase nucleus**. Like other cellular structures, living unstained nucleus does not show much internal differentiation. For detailed study of nucleus, the cells must be properly killed, fixed and stained.

Nucleus is the largest cell organelle. Though first observed by Leeuwenhoek in red blood corpuscles of fish, nucleus was first studied in orchid root cells by Robert Brown in 1831. A nucleus is present in all living eukaryotic cells with the exception of mature sieve cells of vascular plants and red blood corpuscles of mammals. Even here a nucleus is present during

the early stages of their development. Presence of hereditary information in the nucleus was proved by the work of Joachim Hammerling (1953) on single celled alga *Acetabularia* (Fig. 8.60).

Number. Commonly cells are **uninucleate**, that is, they possess a single nucleus. The protistan *Paramecium caudatum* has two nuclei (**binucleate**), macronucleus for controlling metabolic activities of the organism and micronucleus possessing hereditary information. **Multinucleate** or polynucleate condition is found in some cells of bone marrow, striated muscles, latex vessels, several fungi and algae. Multinucleate animal or protistan cells are called **syncytial cells** (*e.g.*, epidermis of *Ascaris*) while in plants and fungi they are called **coenocytic cells** (*e.g., Rhizopus, Vaucheria*). Acellular slime moulds have a multinucleate protoplasmic body called **plasmodium.**

Position. Nucleus is usually found in the region of maximum metabolic activity in the cytoplasm. Commonly it is situated in the geometric centre of the cell. In plant cells it is pushed to peripheral position on one side due to the development of a large central vacuole. Nucleus is peripheral in fat-storing cells or adipocytes, and basal in glandular cells. It is suspended in central vacuole by cytoplasmic strands in *Spirogyra*.

Shape. The nuclei are generally rounded in outline. They appear oval or elliptical in plant cells having large central vacuoles. Disc-shaped nuclei occur in the cells of squamous epithelium, lobed in white blood corpuscles and irregularly branched in silk spinning cells of insects.

Biochemical Analysis. DNA– 9–12%. RNA– 5%. Lipids– 3%. Basic Proteins– 15%. Acid proteins, neutral proteins and enzymes– 65%. Traces of minerals like Calcium, Magnesium, Potassium and Sodium (Phosphorus is a constituent of **DNA, RNA** and acid proteins).

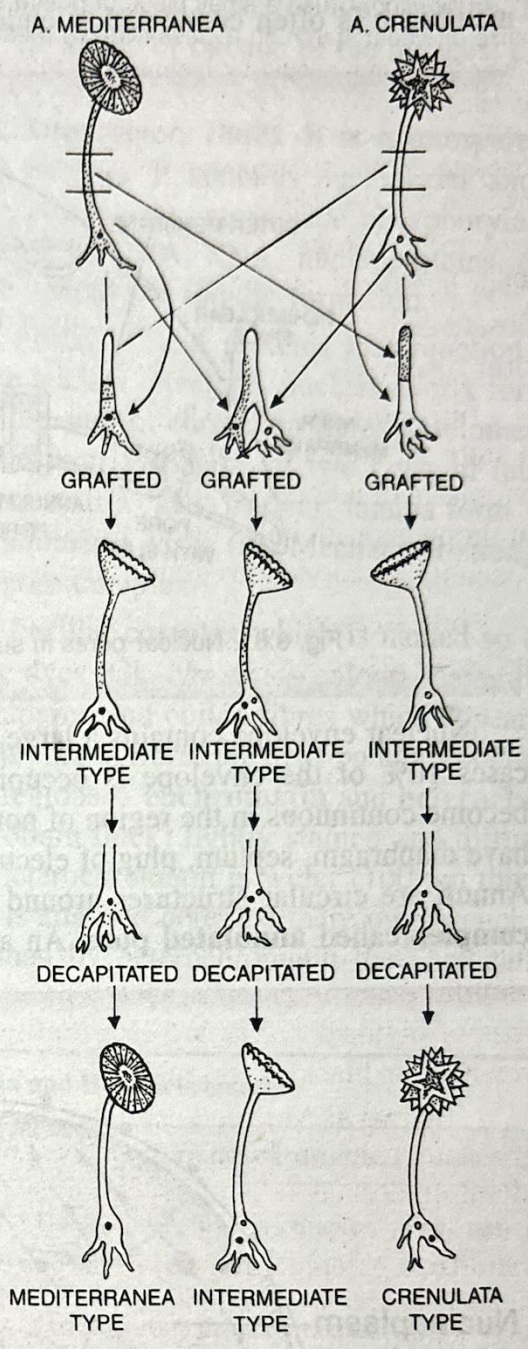

Fig. 8.60. Hammerling's Grafting experiment on *Acetabularia* to show the influence of nucleus on the morphology and development of plant.

Ultrastructure. A typical interphase nucleus is 5–25 μm in diameter. It is differentiated into five parts— nuclear envelope, nucleoplasm, nuclear matrix, chromatin and nucleolus (Fig. 8.61).

1. **Nuclear Envelope** (= Karyotheca). It bounds the nucleus on the outside. The nuclear envelope separates the nucleus from the cytoplasm. It is made up of two lipoprotein and trilaminar membranes, each of which is 60–90Å thick. The inner membrane is smooth. The outer membrane may be smooth or its cytoplasmic surface may bear ribosomes like the rough endoplasmic reticulum. The two membranes of the nuclear envelope are separated by

an electron transparent **perinuclear space**. The space is 100–500 Å in width. The outer membrane is often connected to endoplasmic reticulum.

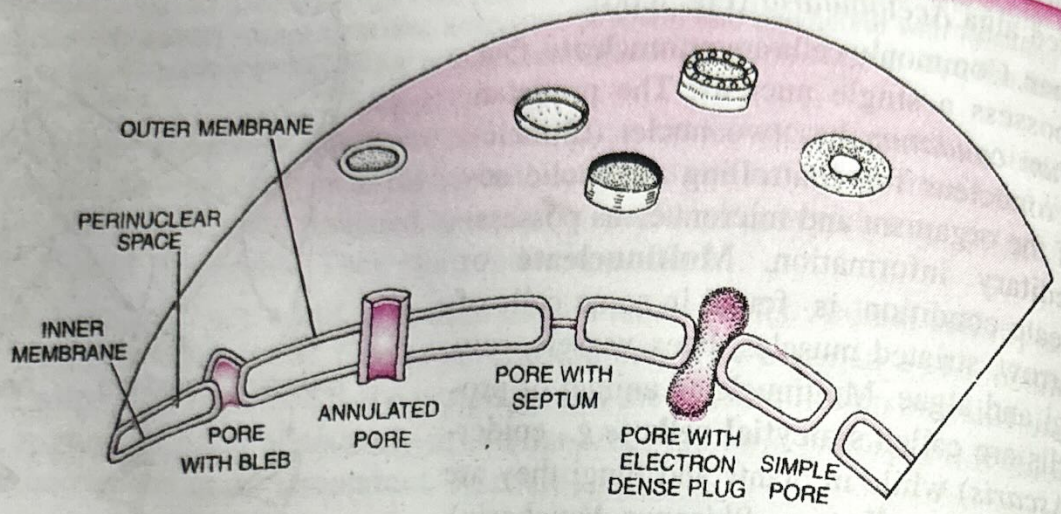

Fig. 8.61. Nuclear pores in surface and sectional views of nuclear envelope.

Nuclear envelope contains a large number of pores or perforations (Fig. 8.61). In some cases 10% of the envelope is occupied by pores. The two membranes of the envelope become continuous in the region of pores. Nuclear pores have complex structure. They may have diaphragm, septum, plug of electron dense material or nucleoplasmin, blebs or annuli. Annuli are circular structures around the pores. The pores and their annuli form a **pore complex** called **annulated pore**. An annulated nuclear pore may possess 9 cylinders, one

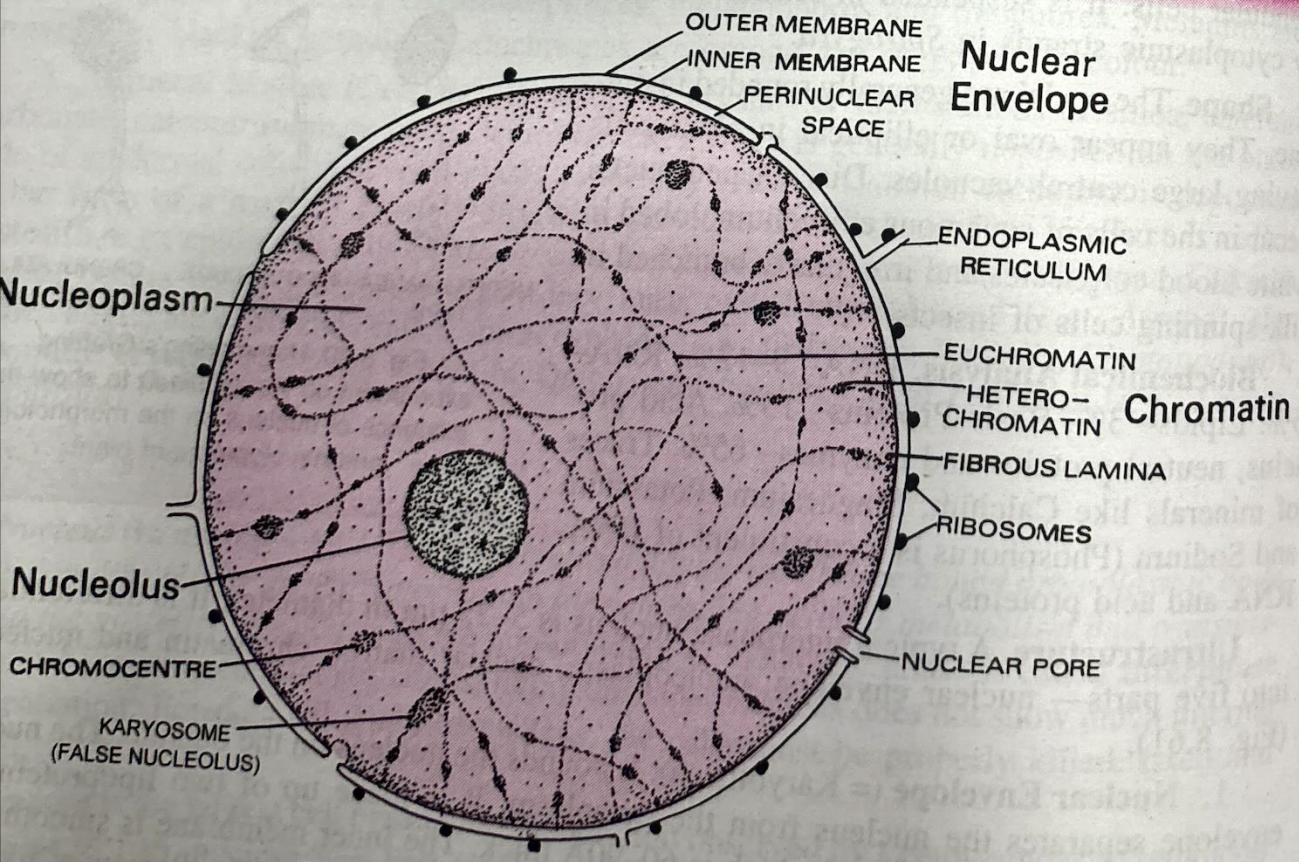

Fig. 8.62. Ultrastructure of interphase nucleus.

central and eight peripheral. Instead, there may be a network of granules and filaments.The nuclear pores control the passage of substances to the inside or outside of the nucleus, *e.g.*, RNAs, ribosomes, proteins.

2. **Nucleoplasm** (Nuclear Sap, Karyolymph, Strasburger, 1882). It is a transparent, semifluid and colloidal substance which fills the nucleus. It contains nucleosides and a number of enzymes (*e.g.*, DNA polymerase, RNA polymerase, nucleoside phosphorylase) which are required for the synthesis and functioning of DNA, RNA, nucleoproteins, etc. Some of the proteins present in nucleoplasm are essential for spindle formation.

3. **Nuclear Matrix.** It is a network of fine fibrils of acid proteins that function as scaffold for chromatin. On the periphery, below the nuclear envelope, nuclear matrix forms a dense fibrous layer called **nuclear lamina**. Terminal ends of chromatin fibres or telomeres are embedded in nuclear or fibrous lamina. Nuclear matrix consists of two types of intermediate filaments, lamin A and lamin B. Nuclear matrix and nuclear lamina form (i) Scaffold for chromatin. (ii) Attachment sites to telomeric parts. (iii) Mechanical strength to nuclear envelope. (iv) Components of nuclear pore complex.

4. **Chromatin**. It is hereditary DNA-protein fibrillar complex which is named so because of its ability to get stained with certain basic dyes (Gk. *chroma*— colour; Flemming, 1879). Chromatin occurs in the form of fine overlapping and coiled fibres which appear to produce a network called **chromatin reticulum**. Chromatin fibres are distributed throughout the nucleoplasm. They are differentiated into two regions— **euchromatin** and **heterochromatin**, Heitz (1928). Euchromatin is narrow (10–30nm thick) lightly stained and diffused fibrous part which forms the bulk of chromatin. Heterochromatin is wider (100 nm thick), darkly stained and condensed granular part which is attached here and there on the euchromatin. Depending upon the size of granules formed by heterochromatin they are called **chromocentres, karyosomes** or **false nucleoli**.

Differences between Euchromatin and Heterochromatin

Euchromatin	*Heterochromatin*
1. It is narrower, 10-30 nm in diameter.	1. Heterochromatin is thicker, 100 nm in diameter.
2. Euchromatin is lightly stained.	2. It is darkly stained.
3. It is somewhat diffused.	3. Heterochromatin is condensed.
4. Euchromatin is fibrous.	4. Heterochromatin is granular.
5. It forms the bulk of chromatin.	5. It is present at certain places in the chromatin.
6. It contains active genes.	6. Heterochromatin does not possess active genes.
7. Euchromatin takes part in transcription.	7. Transcription is absent in heterochromatin.
8. Euchromatin is affected by a number of factors like *p*H, temperature and hormones.	8. Heterochromatin is not influenced by these factors.
9. Crossing over is quite common.	9. Hetertochromatin inhibits crossing over.
10. It replicates early.	10. It replicates late in the S-phase.
11. Nucleosome strand has minimum coiling.	11. Nucleosome strand has solenoid coiling.

The whole of chromatin is not functional. Generally only a portion of euchromatin which is associated with acid proteins takes part in transcription or formation of RNAs.

During prophase of nuclear division, the chromatin fibres condense to form a definite number of thread-like structures called chromosomes.

Differences between Chromatin and Chromosomes

Chromatin	*Chromosomes*
1. It is uncondensed part of nucleoprotein complex.	1. Chromosomes are condensed parts of the nucleoprotein complex.
2. Chromatin is observable in the interphase nucleus.	2. Chromosomes are observable during M-phase or nuclear division.
3. Chromatin is in the form of fine fibrils that run throughout the nucleus.	3. Chromosomes are in the form of short thick threads or rods.
4. Replication occurs in the chromatin phase.	4. It cannot occur in chromosome phase.
5. The replicas are not discernible.	5. Replicas are visible as chromatids.
6. It is active in controlling metabolism and other activities of the cell.	6. Chromosomes are mainly meant for distribution of genetic information to the daughter cells.

5. **Nucleolus** (plural– nucleoli). It was first discovered by Fontana in 1781, described by Wagner in 1840 and provided with its present name by Bowman in 1840. Nucleolus is a naked, round or sightly irregular structure which is attached to the chromatin at a specific region called **nucleolar organiser region** (NOR). Commonly 1–4 nucleoli are found in a nucleus. Upto 1600 nucleoli are reported in the oocytes of *Xenopus*.

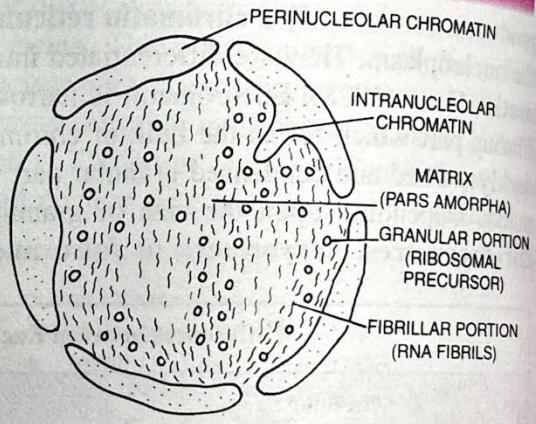

Fig. 8.63. Detailed structure of nucleolus.

A covering membrane is absent around nucleolus. Calcium seems to be essential for maintaining its configuration. Nucleolus has four components— amorphous matrix, granular part, fibrillar portion and chromatin (Fig. 8.63).

(a) *Amorphous Matrix*. It is the homogeneous ground substance of the nucleolus. Matrix is formed of protein.

(b) *Granular Portion*. It consists of granules of the size of 150–200 Å which lie scattered in the amorphous matrix. The granules are formed of protein and RNA in the ratio of 2 : 1. They are believed to be precursors of ribosomes.

(c) *Fibrillar Portion* (Nucleolonema). It is formed of a large number of small fibrils that are 50—80 Å long. The fibrils are made up of both protein and RNA and are believed to be precursors of granules.

(d) *Chromatin Portion*. It is that part of chromatin which is associated with nucleolus. Depending upon its position nucleolar chromatin is of two types— perinucleolar and intranucleolar. The perinucleolar chromatin lies around the periphery of the nucleolus. It gives rise to ingrowths or trabeculae which produce the intranucleolar chromatin.

(i) Nucleolus is the principal site for the development of ribosomal RNAs. (ii) It is the centre for the formation of ribosome components. (iii) Nucleolus stores nucleoproteins. The same are synthesised in the cytoplasm (over the ribosomes) and transferred to nucleolus. (iv) It is essential for spindle formation during nuclear division.

Functions. Nucleus is an essential and integral part of the eucaryotic cell. It stores genetic information in its DNA molecules which can be passed on to daughter cells. It also controls cellular activities.

1. *Chromatin*. Nucleus contains hereditary material called chromatin. Chromatin is DNA-protein complex. It is made of a number of fine fibres that condense to form chromosomes. Number of chromosomes is fixed for a species. They bear genes.

2. *Genetic Information*. Chromatin part of nucleus possesses all the genetic information that is required for growth and development of the organism, its reproduction, metabolism and behaviour (Hammerling, 1953).

3. *Cellular Activities*. Nucleus controls cell metabolism and other activities through the formation of RNAs (mRNA, rRNA, tRNA) which control synthesis of particular type of enzymes.

4. *Ribosomes*. Ribosomes are formed in nucleolus part of the nucleus.

5. *Variations*. All variations are caused by changes in genetic material present in the nucleus.

6. *Cell Growth and Maintenance*. With the help of RNAs, nucleus directs the synthesis of some structural proteins and chemicals required for cell growth and maintenance.

7. *Cell Differentiation*. It directs cell differentiation by allowing certain particular sets of genes to operate.

8. *Cell Replication*. Replication of nucleus is essential for cell replication.

Differences between Cytoplasm and Nucleoplasm

Cytoplasm	*Nucleoplasm*
1. It is the general mass of protopasm which lies outside the nucleus.	1. It is the general mass of nucleus.
2. Cytoplasm is surrounded by a single membrane envelope called plasmalemma.	2. Nucleoplasm is covered on the outside by double membrane envelope called nuclear envelope.
3. The outer part of the cytoplasm is clear and gel-like and is called ectoplasm.	3. Sol-gel differentiation is not clear.
4. A dense fibrous lamina-like structure is absent.	4. Nucleoplasm contains a fibrous matrix. Its outer part is dense and forms fibrous lamina in contact with nuclear envelope.
5. Cytoplasm possesses a number of organelles and supporting structures.	5. The nucleoplasm contains three structures–chromatin, matrix and nucleolus.
6. It is under constant motion or cyclosis.	6. Cyclosis or streaming is absent.
7. The fluid part of cytoplasm contains a number of chemicals like minerals, nucleotides, amino acids, sugars, proteins and enzymes.	7. Nucleoplasm possesses small amount of minerals, sugar and amino acids. There are abundant nucleosides, nucleotides, proteins and enzymes.
8. It contains endomembranes.	8. Endomembranes are absent.
9. It is site of ribosome functioning.	9. It is site of ribosome formation.
10. Cytoplasm is the part of cell connected with various metabolic activities and functions.	10. Nucleoplasm is part of cell, that contains genetic material for controlling cytoplasmic structure and function.
11. It forms the bulk of cells.	11. It forms a small part of cell.

CHROMOSOMES

They are rod shaped or threadlike deeply stainable condensed chromatin fibres which are hereditary vehicles as they store and transmit coded hereditary information. Chromosomes appear only during karyokinesis. They are meant for equitable distribution of genetic material.

The number is fixed and is the same in all the individuals of a species. There is a single set in gametophytic or haploid forms and two sets in sporophytic or diploid forms. Size and shape of individual chromosomes are quite distinct. The shape is more clearly visible in late prophase and metaphase (as well as anaphase) when primary constriction or centromere becomes distinct. During prophase and metaphase, the chromosomes are replicated. There are two chromosome halves or **chromatids**. The two chromatids are attached to each other by a narrow area called **centromere** or **primary constriction**. Anaphasic chromosomes do not have chromatids. The two parts of a chromosome or chromatid on either side of primary constriction are called **arms**. The two arms are equal in **isobrachial chromosomes** and unequal in **heterobrachial chromosomes**. The ratio between the two arms of a chromosome is called **centromeric ratio**. Based on the position of centromere, chromosomes are of four types (Fig. 8.64): (i) **Telocentric**. Centromere terminal in the area of telomere. (ii) **Acrocentric**. Centromere inner to telomere (= subterminal). (iii) **Submetacentric.** Centromere submedian (iv) **Metacentric.** Centromere median.

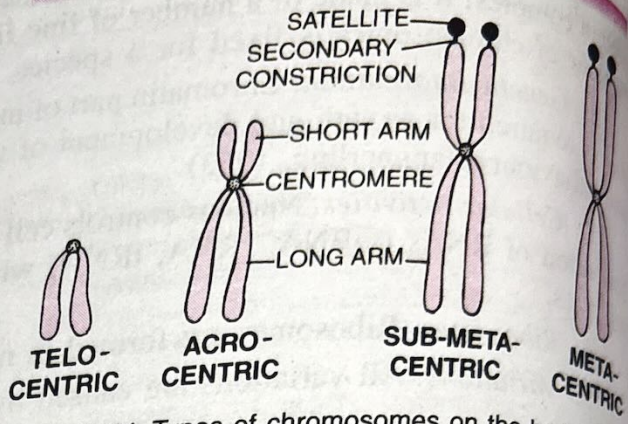

Fig. 8.64. Types of chromosomes on the basis of position of centromere.

Besides primary constriction or centromere, a chromosome may have one or more secondary constrictions. A secondary constriction present near the distal part of an arm may develop a small outgrowth or fragment called **satellite**. Satellite is connected to secondary constriction through a chromatin thread. A chromosome having satellite is called **sat chromosome**. Sat chromosomes are called **marker chromosomes**. Other secondary constrictions can also function as markers because they occupy a constant position.

Under light microscope, cytologists found that a chromosome contains a coiled filament called **chromonema**. Chromonema was thought to be gene bearing part. Some workers thought that a chromosome may have several chromonemata. Electron microscope has revealed that a chromosome is actually formed by direct condensation of a single chromatin fibre attached to a scaffold. It is 30 nm in diameter and contains a single DNA duplex.

Giant Chromosomes

They are of two types, polytene and lampbrush.

Polytene Chromosomes (Gk. *Polys*– many, *tainia*– threads; Kollar, 1882). Polytene chromosomes were first reported by E.G. Balbiani in 1881. They are quite common in salivary glands of insects and are, therefore, popularly called **salivary chromosomes**. Polytene chromosomes also occur in other organs of insects, antipodal cells (of embryo sac), endosperm cells and suspensor cells of embryo (Nagl, 1974; Malik and Singh, 1979). The chromosomes can reach a length of 2000 μm and contain 1000 (*Drosophila*) to 16000 (*Chironomus*) times DNA as compared to the ordinary somatic chromosomes. Polytene chromosomes are multistranded. They are in permanent prophase stage. The giant chromosomes are formed by **somatic pairing** between homologous chromosomes and repeated replication (endomitosis) of their chromonemata.

All the polytene chromosomes may remain attached to one another at a common point called chromocentre. It represents pericentromeric heterochromatin which is slow to rep-

licate. Polytene cells and their nuclei are large-sized. Polytene cells cannot divide further. They ultimately die. The adult organs develop from some small-sized diploid cells lying nearby.

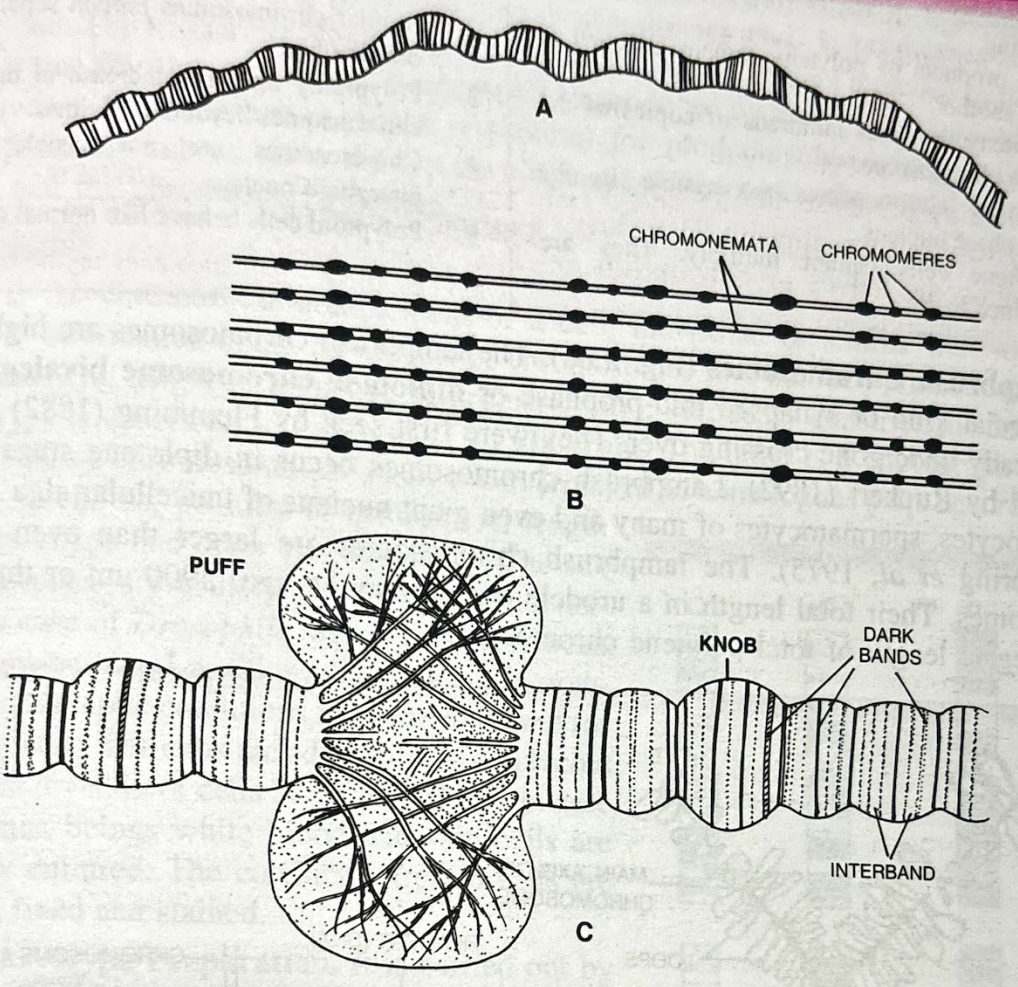

Fig. 8.65. Polytene chromosome. A, a typical polytene chromosome. B, schematic representation of formation of a polytene chromosome and its dark bands by coming together of a number of chromonemata and their chromomeres. C, an enlarged portion of polytene chromosome showing a puff.

Depending upon their reaction to basic dyes, the polytene chromosomes bear a number of dark **bands** of various sizes and intensity. They are separated by light areas called **interbands**. The dark bands are presumed to be formed by the juxtaposition of chromomeres of the different chromonemata of a polytene chromosome (Fig. 8.65 B).

In certain developmental stages the polytene chromosomes bear conspicuous swellings called chromosome **puffs** (Fig. 8.65 C). The larger swellings are called **Balbiani rings**. In the region of a puff or Balbiani ring, the DNA strands uncoil, become active and produce number of copies of messenger or mRNA. The mRNAs may remain temporarily stored in the puff. Puffs are not permanent. At different physiological or developmental stages different bands uncoil to produce puffs. Puffs are withdrawn after the completion of the stage. By correlating puffs with different physiological or developmental processes scientists have been able to locate genes on the polytene chromosomes and prepare chromosome maps.

Differences between Polyteny and Polyploidy

Polyteny	*Polyploidy*
1. Homologous chromosomes undergo somatic pairing.	1. Pairing of homologous chromosomes does not occur in somatic cells.
2. The products of polyteny remain attached to one another.	2. Similar chromosomes remain separate from one another.
3. Polyteny produces hundreds of copies of the same chromosome.	3. Polyploidy does not increase in number of chromosomes beyond 6-10 times.
4. Polytene chromosomes are visible in the interphase nucleus.	4. Chromosomes are not visible in the interphase nucleus.
5. Polytene cells cannot multiply. They are destined to die.	5. Polyploid cells behave like normal cells.

Lampbrush Chromosomes (Fig. 8.66). The lampbrush chromosomes are highly elongated special kind of synapsed mid-prophase or **diplotene chromosome bivalents** which have already undergone crossing over. They were first seen by Flemming (1882) but were described by Ruckert (1892). Lampbrush chromosomes occur in diplotene stage of most animal oocytes, spermatocytes of many and even giant nucleus of unicellular alga *Acetabularia* (Spring *et al*, 1975). The lampbrush chromosomes are larger than even polytene chromosomes. Their total length in a urodele oocyte may be upto 5900 μm or three times the aggregate length of total polytene chromosomes.

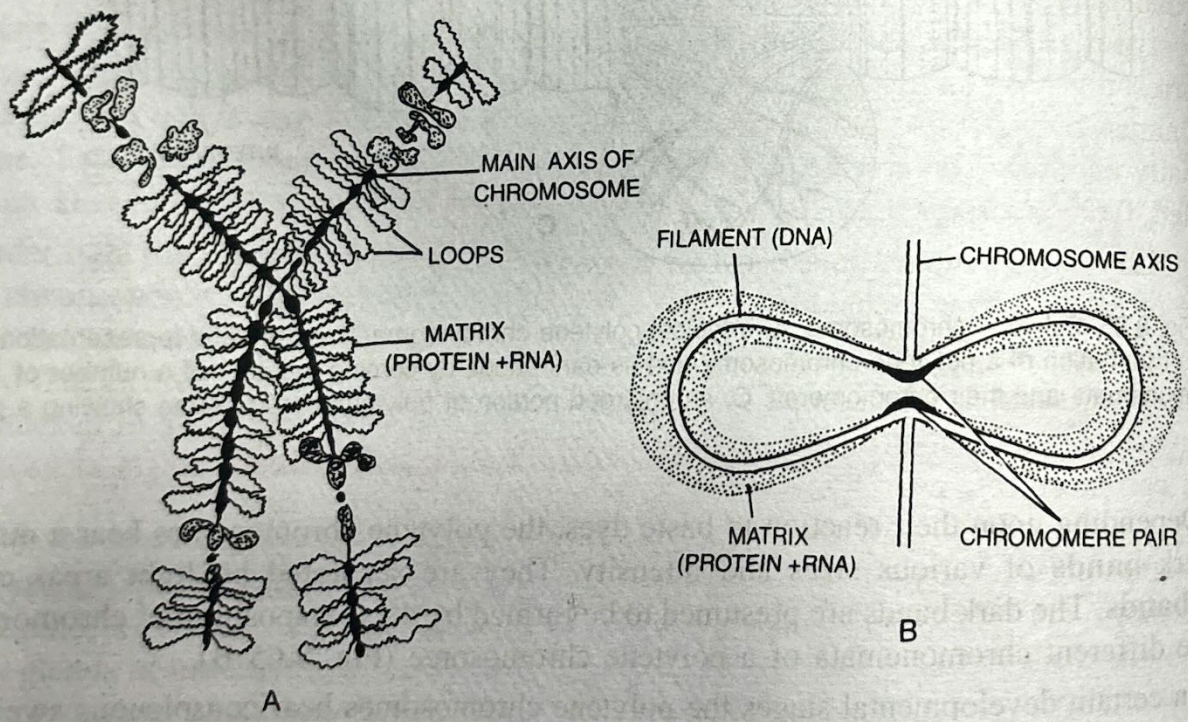

Fig. 8.66. Lampbrush chromosome . A, Enlarged view of a part of lampbrush chromosome. B, One loop of a lampbrush chromosome.

Lampbrush chromosomes occur in pairs. The pair consists of homologous chromosomes which are joined at certain contact points called **chiasmata**. Each chromosome has a double main axis due to presence of two elongated chromatids. Both the chromatids bear rows of large number of chromomeres. Two adjacent chromomeres are separated by interchromomeric stretches. Many of the chromomeres give out **lateral** projections or

loops. The lateral loops provide a test tube or lampbrush-like appearance to the chromosome pair. Length of a lateral loop may vary from 5–100 μm. Loops are uncoiled or expanded parts of a chromomere with one to several transcriptional units. Usually a lateral loop has a thin or uncoiling part and a thick or coiling part. Lateral loops take part in rapid transcription of mRNA meant for synthesis of yolk and other substances required for growth and development of meiocytes. RNA synthesis begins at the thinner end. It progresses towards the thicker end. The transcripts alongwith their binding proteins remain attached to the loop and give it a fine fibrillar appearance. Some mRNAs produced by lampbrush chromosomes may be stored as **informosomes** (mRNA + protein) for producing biochemicals during early development of embryo. After the full development of meiocytes, the lateral loops are withdrawn and the chromosomes shorten.

Karyotype

It is the chromosome complement of a cell, individual or similar individuals which provides information about all aspects of chromosomes like number, relative size, position of centromere, length of arms and centromeric ratio, secondary constrictions and satellites. Karyotype is described in the form of an **idiogram**. The latter is a photograph or diagram of metaphasic chromosomes of an organism arranged in homologous pairs according to their length, thickness, position of centromere, length of arms, shape and other characteristics. The sex chromosomes are usually placed at the end (except in case of *Drosophila* where they have been given the number I position). Cultured cells growing under aseptic conditions are generally used for karyotyping. The cells are administered colchicine to arrest division of cells at the metaphase. In case of human beings white blood and skin cells are usually cultured. The colchicine treated cells are killed, fixed and stained.

Karyotype Preparation. It is carried out by one of the following techniques.

1. **Banding Technique** (Fig. 8.67). Chromosomes are stained with special flourescent dyes that have differential affinity for different parts of the chromosomes. It brings about specific banding pattern. Bands are segments of stained chromosomes that appear lighter, darker or stained as compared to adjacent parts. Chromosome banding was discovered by Caspersson *et al* (1970). With one particular dye, the chromosomes show a particular unique banding pattern, *i.e.*, the banding pattern is constant with a particular treatment. There are many types of staining techniques which show different banding patterns (Fig. 8.67). The four types of banding techniques used in animal karyotyping are as follows : (i) **C-Banding** (C-Staining). It stains regions having constitutive heterochromatin (*e.g.*, pericentromeric regions).

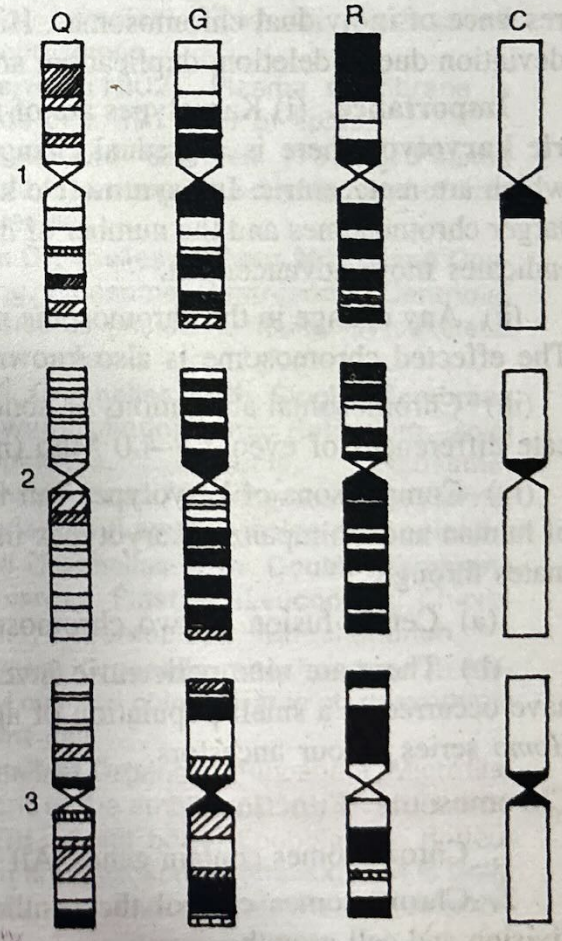

Fig. 8.67. Banding patterns of first three (largest) human chromosomes in response to various staining techniques : Q-Quinacrine. G-Giemsa. R-Reverse Giemsa. C-Constitutive heterochromatin.

The chromosomes are first treated with strong alkali. DNA is then denatured with trisodium citrate. It is followed by staining with Giemsa. (ii) **Q-Banding** (Q-Staining). Treatment with quinacrine mustard and observation with fluorescent microscope brings out AT rich regions. It was the first fluorescent staining technique developed by Caspersson *et al.* Q-banding technique stains Y-chromatin in the interphase nucleus of human males. (iii) **G-Banding** (Giemsa Staining). Chromosomes incubated in saline solution are stained with Giemsa. It brings out sulphur-rich protein parts. Ordinary light microscope can be used. G-banding is absent in plant chromosomes. (iv) **R-Banding** (R-Staining). Chromosomes incubated in buffer at high temperature are treated with Giemsa to produce bands in sulphur deficient regions (hence reverse Giemsa).

In plant karyotyping, C-banding and N-banding are commonly used.

2. **In Situ Hybridisation.** DNA probes labelled with radioactive and non-radioactive molecules are employed to locate specific DNA sequences over the chromosomes. The process is called **fluorescence in situ hybridisation** or **FISH**. In **multicolour fluorescence in situ hybridisation** (Mc FISH) DNA probes are also labelled with fluorochromes to locate the position of different DNA sequences on the same chromosome.

3. **Flow Cytometry.** Thousands of chromosomes are obtained from cultured cells. A suspension is prepared of them. DNA binding fluorochrome is added to the suspension to stain the chromosomes. Chromosomes are passed through cytometer which measures fluorescence of individual chromosomes. Histogram is prepared which can indicate even slight deviation due to deletion, duplication, aneuploidy, etc.

Importance. (i) Karyotypes are of two kinds, symmetric and asymmetric. In **symmetric karyotype** there is a gradual change from smallest to largest chromosomes, most of which are metacentric. In **asymmetric karyotype** there is a large gap between smaller and larger chromosomes and the number of metacentric chromosomes is fewer. High asymmetry indicates more advancement.

(ii) Any change in the chromosome number (extra or deficient) is detected immediately. The effected chromosome is also known at a glance.

(iii) Chromosomal aberrations or abnormalities are found out. Flow cytometry can indicate differences of even 1.5–4.0 Mbp (mega base pair).

(iv) Comparisons of karyotypes can indicate relationship amongst species. Comparison of human and Chimpanzee karyotypes indicates that human beings have evolved from primates through :

(a) Cenric fusion of two chromosomes to form chromosome number 2.

(b) There are nine pericentric inversions and two duplications. These changes must have occurred in a small population of apes making them genetically isolated and forming *Homo* series of our ancestors.

Chromosome Functions

1. Chromosomes contain genes. All the hereditary information is located in the genes.
2. Chromosomes control the synthesis of structural proteins and thus help in cell division and cell growth.
3. They control cellular differentiation.
4. By directing the synthesis of particular enzymes, chromosomes control cell metabolism.
5. Chromosomes can replicate themselves or produce their carbon copies for passage to daughter cells and next generation.

6. Sat chromosomes produce nucleoli for synthesis of ribosomes.
7. Their haploid or diploid number respectively bring about gametophytic and sporophytic characteristics to the individual.
8. Chromosomes form a link between the offspring and the parents.
9. Some chromosomes called sex chromosomes (*e.g.*, X and Y or X and 0) determine the sex of the individual.
10. Through the process of crossing over, chromosomes introduce variations.
11. Mutations are produced due to change in gene chemistry.

ADDITIONAL INFORMATION

- G.N. Rama Chandran (1922-2001) was an outstanding figure in the field of protein structure. He discovered triple helical structure of collagen protein with the help of his graphic technique called Ramachandran Plot.
- **Smallest Human Cells.** Erythrocytes— 6 - 8 μm in diameter. Blood platelets are 2 - 3 μm in diameter but they are considered to be cell fragments instead of being cells themselves.
- **Plasmodium Sporozoite.** 2 μm in length.
- **Size of Human Gametes.** Human sperm is 60 μm in length while human egg is 100 μm in diameter.
- **Dual Existence.** Cells of multicellular organisms have dual existence, one for themselves and the other as components of the individual.
- **Membrane Channels.** They are of two main types, **aqueous channels** for the passage of water and **ion channels** for the passage of ions. Nehar and Sakmann were awarded Nobel Prize (1991) for discovery of single ion channels.
- **Membrane Fluidity.** It increases with the increase in number of lipids with unsaturated fatty acids and small chain fatty acids. While tails of the former possess kinks, the tails of the latter develop only weak bonds.
- **Microvilli.** They do not increase absorptive surface area. Microvilli are regions with high mechanical strength. Absorption occurs through pinocytosis in the depressions between adjacent microvilli.
- **Lewis** (1931). Discovered pinocytosis. Pinosomes are small and are not visible under optical microscope.
- **Metchnikoff** (1883). Discovered phagocytosis.
- **Adsorptive Pinocytosis.** It occurs in case of macromolecules like proteins. Membranes possess special receptor areas for them. As soon as the macromolecule attaches to the receptor site, the latter invaginates to form pinosome. Not much fluid is taken in. These pinosomes are directly passed to the region of use like Golgi complex. They are also called **receptosomes.**
- **Overton** (1902). Plasma membrane is made of a thin layer of lipids.
- **Gorter and Grendell** (1926). Plasma membrane contains a double layer of lipid molecules.
- **Cell Organelles Without Membrane Covering.** Ribosome, Centrosome, Centriole, Nucleolus (inside nucleus), Cytoskeletal Structures.
- **Cell Organelles With Single Membrane Covering.** Endoplasmic Reticulum, Golgi Apparatus, Vacuole, Lysosome, Sphaerosome, Peroxisome, Glyoxysome, Thylakoid (Lamella, inside chloroplast).
- **Cell Organelles With Double Membrane Covering.** Plastids (Leucoplast, Chloroplast, Chromoplast), Mitochondrion.
- **Largest Organelle** mitochondrion in animal cell and chloroplast in photosynthetic plant cell.
- **Smallest Organelle.** Ribosome, Microfilament is the smallest structure.
- **GERL.** Golgi body, Endoplasmic Reticulum and Lysosome complex. **GER** is Golgi body and Endoplasmic Reticulum complex.
- **Medium for free Cell Organelles.** Cell organelles cannot be kept in water because they would burst like erythrocytes kept in water. Cell organelles can be maintained only in solution of specific concentration like 0.25% sucrose solution.

- **Ergastoplasm.** Endoplasmic reticulum of Garnier (1897).
- **Ergasome.** Polyribosome.
- **Ergastic Substances.** Cell inclusions.
- **Cellulose Microfibrils.** Each microfibril is formed of 20 elementary fibrils or micelles with each of the latter having about 100 cellulose molecules. Some 250 microfibrils may aggregate to produce a single macrofibril. A cotton fibre has 1500 macrofibrils (= fibrils).
- **Chloroplasts.** They are of two types, agranal (without grana) and granal (with grana). Agranal choroplasts occur in bundle sheath cells of C_4 plants, algae and **bryophytes**.
- **Transfer Cells.** They are plant cells specialised in transfer of solutes.
- **Leeuwenhoek.** He was the first to observe many cellular structures including nucleus and chloroplasts, but is not credited with their discovery.
- **Apoptosis.** Genetically controlled cell death.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. Which of the following is not correct ? (a) Robert Brown discovered the cell. (b) Schleiden and Schwann formulated the cell theory. (c) Virchow explained that the cells are formed from pre-existing cells. (d) A unicellular organism carries out its activities within a single cell.
   ✓ (a)
2. New cells generate from (a) Bacterial fermentation (b) Regeneration of old cells (c) Pre-existing cells (d) Abiotic materials.
   ✓ (c)
3. Match the following :

Column I	*Column II*
(a) Cristae	(i) Flat membranous sacs in stroma
(b) Cisternae	(ii) Infolding
(c) Thylakoids	(iii) Disc-shaped sacs in Golgi apparatus.

   ✓ (a) –(ii), (b) –(iii), (c) –(i)
4. Which of the following is correct ? (a) Cells of all living organisms have a nucleus. (b) Both animal and plant cells have a well defined cell wall. (c) In prokaryotes there are no membrane bound organelles. (d) Cells are formed *de novo* from abiotic materials.
   ✓ (c)
5. What is a mesosome in a prokaryotic cell ? Mention the function that it performs.
   ✓ Mesosome is a membrane complex formed by infolding of plasma membrane in prokaryotic cells. A mesosome may be attached to nucleoid when it is called **septal mesosome**. A mesosome free from nucleoid is known as **lateral mesosome**. Lateral mesosome is often called **chondrioid** as it is rich in respiratory enzymes. Septal mesosome takes part in separation of daughter nucleoids, formation of plasma membrane for rapid elongation and septum formation.
6. How do neutral solutes move across the plasma membrane ? Can the polar molecules also move across it in the same way ? If not, then how are these transported across the membrane ?
   ✓ **Neutral solutes** are able to directly pass through the lipid bilayer of plasma membrane as they are lipid soluble. Rate of movement depends upon concentration gradient and lipid solubility of the neutral solutes.
   Polar molecules require special hydrophilic areas for their passage. The same are provided by three types of transport mechanisms— ion, channels, permeases and ATP energised carrier proteins (for active transport).
7. Name two cell organelles that are double membrane bound. What are the characteristics of these two organelles ? State their functions and draw labelled diagrams of both.
   ✓ **Cell Organelles with Double Membrane Covering.** Mitochondria and chloroplasts (also leucoplasts, chromoplasts).
   Mitochondria. Characteristics. (i) They are cylindrical or sausage shaped cell organelles which can be stained differentially by Janus Green. (ii) The inner membrane is thrown into folds called **cristae**. (iii) Inner membrane has **ETC** (electron transport chain) as well as elementary particles or **oxysomes** ($F_0 - F_1$ particles). (iv) There are two chambers, outer and inner. (v) Inner chamber has matrix containing DNA, RNA, ribosomes, enzymes of Krebs cycle, amino acid synthesis, fatty acid

synthesis, calcium and manganese. (vii) Mitochondria are simi-autonomous due to presence of their own DNA, ribosomes and RNA.

Functions. Refer to the text.

Chloroplasts. Characteristics. (i) They are green coloured plastids which are disc-shaped in higher plants but variously shaped in lower plants. (ii) The structural units of chloroplasts are membrane lined flattened sacs called **thylakoids**. (iii) At places the thylakoids are short and stacked. They are called **grana**. (iv) Photosynthetic pigments are located over thylakoid membranes. (v) Thylakoids possess electron transport chains and coupling factors for synthesis of ATP. (vi) Matrix of a chloroplast contains DNA, RNA, ribosomes and enzymes. Temporary starch grains and lipid containing plastoglobuli also occur. (vii) DNA, RNA and ribosomes make the chloroplasts semi-autonomous.

Functions. Refer to the text.

8. Multicellular organisms have division of labour. Explain.

✓ Division of labour is differentiation of certain components or parts to perform different functions for increased efficiency and higher survival. Multicellular organisms often possess millions of cells. All the cells are not similar. The cells present on the surface are dead and impermeable to protect the internal cells from harsh external environment. They also form structures for offence and defence of the organism.

Every cell of a multicellular organism cannot obtain food from outside. The organism requires a system for obtaining food, its digestion and distribution. Therefore, a digestive system and system of transport are also required.

Certain cells of the body take over the function of reproduction. Others take part in repair and replacement of worn out or injured portions.

For optimum functioning of cells, a multicellular organism also comes to have an internal favourable environment.

Therefore, multicellular organisms come to have division of labour.

9. What are nuclear pores ? State their function.

✓ Nuclear pores (Callan and Tomlin, 1950) are perforations present in the nuclear envelope. Their number and size vary in different organisms and their cells. A nuclear pore may be simple channel or have extra structures like diaphragm, septum, bleb, plug of nucleoplasmin or annuli (= microcylinders). Pore having extra structures is called annulated pore or pore complex.

Functions. Nuclear pores regulate the passage of substances to the inside and outside the nucleus, *e.g.,* enzymes, RNA, ribosome units, proteins.

10. Both lysosomes and vacuoles are endomembrane structures, yet they differ in terms of their functions, comment.

✓ Endomembrane system is an intracellular membrane system which is connected by flow of membranes and materials from one part to the other with the help of vesicles. Components of endomembrane system are endoplasmic reticulum, plasma membrane, Golgi apparatus, lysosomes and vacuoles. However, each component is specialised to perform distinct functions which may be elaboration of materials supplied by another. Lysosomes are specialised to perform intracellular digestion while vacuoles are meant for storage of materials, both waste and extra.

11. Describe the structure of the following with the help of labelled diagram (i) Nucleus (ii) Centrosome.

✓ **(i) Nucleus.** It is a double membrane covered protoplasmic body that contains the genetic material. Nucleus is generally rounded or oval – elliptical in outline with a diameter of 5–25 µm. It has five parts — nuclear envelope, nucleoplasm, nuclear matrix, chromatin and nucleolus.

Nuclear Envelope. It is a double membrane covering of nucleus. The outer membrane is connected with E.R. Ribosomes often occur over its surface. A narrow perinuclear space is found between the two membranes. A number of pores called **nuclear pores** occur in the membrane. They often possess regulating structures like blebs, diaphragm, annuli, microcylinders, septum or electron dense material called nucleoplasmin. Nuclear pores allow passage of seleted materials into and outside the nucleus. (Refer Fig. 8.62).

Nucleoplasm (Nuclear Sap). It is colloidal semifluid complex having nucleosides, enzymes, proteins and factors required for functioning of genetic material.

Nuclear Matrix. It is a proteinaceous fibrous scaffold for chromatin. On the periphery, there is a dense fibrous layer of **nuclear lamina** for providing attachment sites to telomeres and mechanical strength to nuclear envelope.

Chromatin. It is a DNA-protein fibrillar complex which appears in the form of a network and is often

called **chromatin reticulum**. Chromatin is dispersed throughout the nucleus. It has a narrow active hightly stained **euchromatin** part and a granular darkly stained inactive heterochromatin part. During cell division, chromatin condenses to form chromosomes.

Nucleolus. It is a rounded or slightly irregular, naked structure attached to chromatin which is specialised to synthesize ribosome subunits. Nucleolus has four parts— amorphous matrix, granular portion, fibrous portion and chromatin part.

✓ **(ii) Centrosome** (Central Apparatus). It is a naked cell organelle found in animal cells and cells of some lower plants that takes part in formation of spindle ad basal bodies of cilia or flagella. A centrosome lies near the nucleus. It has a nongranular cytoplasmic region called centrosphere and two cylindrical structures named centrioles. The two centrioles lie at right angles to each other. Each centriole has a whorl of nine **triplet fibrils** of fused microtubules that run parallel to one another but at an angle of 40°. The centre of the centriole has a proteinaceous rod called **hub**. Hub is connected to peripheral triplets by means of proteinaceous strands known as **spokes.** A thickening called *X* is present on the spoke near the triplet. Another thickening *Y* is found nearby. *Y* is attached to *X* as well as C–A linker between the adjacent triplets. The whole complex gives a cart-wheel appearance. (Fig. 8.58).

Each centriole is surrounded by dense amorphous protoplasmic masses called **massules** or pericentriolar satellites. They function as nucleating centres for growth of new fibrils during formation of aster and daughter centrioles.

12. What is centromere ? How does the position of centromere form the basis of classification of chromosomes. Support your answer by showing the position of centromere on different types of chromosomes.

✓ **Centromere.** Centromere or primary constriction is a narrow lightly stained area of the chromosome where two chromatids are attached to each other. It also provides site over its surface for attachment of chromosome fibre. (Fig. 8.64)

Based on position of centromere, chromosomes are of four types— (i) **Metacentric.** Centromere median. (ii) **Submetacentric.** Centromere submedian. (iii) **Acrocentric.** Centromere subterminal. (iv) **Telocentric.** Centromere in the area of telomere.

13. What are characteristics of prokaryotic cells ?

✓ Refer to the text.

14. Cell is a basic unit of life. Discuss in brief.

✓ Refer to the text

TEST QUESTIONS

One Mark Questions (With Answers)

1. Who built the very first microscope ?

✓ Zacharias Janssen in 1590.

2. What are embryoids ?

✓ Embryoids are nonzygotic embryo like structures which are formed *in vitro* cultures and have the potential to develop into full fledged plants.

3. Why are the eggs usually large sized cells ?

✓ In general, eggs are large sized cells because they store food for the partial or complete development of the embryo.

4. What is the chemical constitution of cell wall matrix ?

✓ Water - 60%, Hemicellulose – 5-15%, Pectic Substances – 2-8%, Lipids – 0.5-3.0%, Proteins - 1-2%.

5. What is plasmalemma ?

✓ **Plasmalemma** or **plasma membrane** is a biomembrane that occurs on the outside of the cytoplasm in both procaryotic and eucaryotic cells.

6. Who proposed the first lamellar model ?

✓ Danielli (1935) and Davson (1935).

7. What is the major function of cell membranes in a eukaryotic cell ?

✓ The major function of cellular membranes is **compartmentalisation.**

8. Which cell organelle helps in the formation of root hair ?

✓ The formation of root hair from their mother cells is believed to take place through the agency of Golgi apparatus.

9. With which cell organelle diastole and systole are associated ?
   ✓ Contractile Vacuoles.
10. Which is the principal site for the development of ribosomal RNAs.?
    ✓ Nucleolus.
11. Does nucleoplasm possess cyclosis ?
    ✓ No, cyclosis or streaming is absent.
12. Who discovered the cell ?
13. Define totipotency.
14. What is meant by cell differentiation ?
15. Who proposed the cell theory ?

Two Mark Questions (With Sample Answers)

16. Write about cellular autonomy in unicellular organisms ?
    ✓ In unicellular organisms the cell has complete independent existence. It is not dependent upon any other cell for any function, material or information. The cell depends upon its own internal or intrinsic information. However, it responds to environment with which it is in direct contact. All life activities are carried out by the same cell. The division of labour is absent.
17. What are the disadvantages of multicellularity ?
    ✓ (i) Specialised cells often lose the power of division so that injury is not repaired, *e.g.*, nerve cells.
    (ii) Regeneration ability of multicellular organisms decreases with specialisation.
    (iii) Specialised cells may lose vital functions in order to carry out specific activity, *e.g.*, RBCs, sieve tube cells.
    (iv) Some unicellular organisms are immortal as their body gets distributed in their offspring. This is not so in case of multicellular organisms. Here only a few germinal cells are involved in reproduction while most cells die with the death of the organism.
18. Write a short note on primary wall ?
    ✔ **Primary Wall.** It is the first formed wall of the cell which is produced inner to the middle lamella. The primary wall is commonly thin (0.1–3.0 μm) and capable of extension. It grows by intussusception or addition of materials within the existing wall. Some cells possess only primary wall, *e.g.*, leaf cells, fruit cells, cells of cortex and pith. Primary wall consists of a number of cellulose **microfibrils** embedded in the amorphous gel-like matrix or ground substance of pectin, hemicellulose and glycoprotein.
19. Explain the structure and function of plasmodesmata with the help of a diagram ?
    ✔ Plasmodesmata are cytoplasmic bridges between adjacent plant cells which develop in the minute pores of their walls. They form a protoplasmic continuum called **symplast.** Various substances can pass from one cell to another through plasmodesmata. A plasmodesma consists of a canal lined by plasma membrane and having a simple or branched tubule known as desmotubule. Desmotubule is an extension of endoplasmic reticulum.
20. Name the two main constituents of the plasma membrane and show how they are arranged by means of a diagram.
21. Give the specific scientific terms for the following
    (a) Cluster of ribosomes found in cytoplasm.
    (b) Extensive infoldings to the inner membrane of mitochondria.
    (c) Stacks of closely packed thylakoids.
    (d) Stalked particles on the inner membrane of the mitochondria.
22. (i) Write a short note on ribosomes.
    (ii) Which organelle has a key role in the transformation and turn over of membranes within the cell?
23. How does a mitochondrion differ functionally from a chloroplast.
24. Give significance of glycocalyx.
25. What are the cell inclusions in a prokaryotic cell ?

Three Mark Questions

26. What are the advantages for an organism to have tissues instead of the one type of cells ?
27. Who proposed the Cell Theory ? Explain the main points of this theory as it stands today.
28. What is the difference between unicellular and multicellular organisms in organisation of their cells?

29. Explain how multicellular organisms possess higher survival value over unicellular organisms.
30. Discuss the modern concept of cell theory.
31. Describe the cell theory.
32. Enumerate the functions of biomembranes.
33. (a) Apart from nucleus, which two other cell organelles have independent DNA ?
    (b) What is the principal site of synthesis of ribosomal RNA ?
34. Distinguish between
    (a) cytoplasm and nucleoplasm ; (b) chromatin and chromosome ; (c) microtubules and microfilaments.
35. Write a note on exocytosis and endocytosis.
36. Which of the following are found exclusively in plant cells, exclusively in animal cells, and in both ?
37. Describe the structure of ribosome ?
38. Differentiate among microtubules, microfilaments and microfibrils.
39. (a) Describe the structure of centriole. ; (b) Mention the main functions of centriole.
40. (a) Define dictyosome. Point out the difference between Golgi apparatus of plant and animal cells.
    (b) Why is Golgi apparatus called Golgi apparatus.
    (c) Name an organism and cell where Golgi apparatus is absent.
41. (a) Which cell organelles are referred to as suicide bags ? Why are they given this name ?
    (b) Mention the scientific contribution of C. de Duve.
42. Write an account of lysosomes and their role in cellular metabolism.
43. Describe the structure and function of peroxisomes.
44. (a) Name the scientists who discovered mitochondria.
    (b) Which is the most indispensable in the life of a cell —mitochondria, chloroplasts or Golgi body ? Why ?
45. What are vacuoles? Name their types and functions.
46. Describe the functions of the three organelles, *viz.* Golgi bodies, chloroplasts and mitochondria.
47. Distinguish between (a) Primary wall and secondary wall ; (b) Leucoplast and chromoplast.
48. Distinguish between prokaryotic and eukaryotic cells.
49. Give the difference between cell walls of Gram-positive and Gram-negative bacteria.

Five Mark Questions

50. Describe the electron microscopic structure of cell wall and state its functions.
51. Describe the electron microscope structure of biomembrane and the two models proposed to explain it.
52. Briefly describe pinocytosis and phagocytosis. Differentiate between the two.
53. Where would the following structures be found in a cell ?
    (a) microtubules (b) thylakoids (c) F_0 -F_1 complex (d) ribosomes (e) nucleolus.
54. List the functions of rough and smooth endoplasmic reticulum and Golgi bodies.
55. Name the various types of plastids. Where do fat soluble pigments occur.
56. Describe with the help of a diagram the structure of Golgi body and state its functions.
57. (a) What is the significance of the presence of naked DNA in mitochondria?
    (b) Mitochondrial ribosomes are similar to prokaryotic ribosomes. Give the significance of this report.
    (c) Mitochondria are the centres of oxidation of respiratory substrates. Why do not they get burnt up by the released energy ?
58. (a) Briefly describe the structure of chloroplast in relation to functions.
    (b) State the chief functions of chloroplast.
59. Describe the fluid mosaic model of plasma membrane.

True or False

60. Indicate which of the following statements are true (T) or false (F).
    (a) Robert Hook discovered the nucleus.
    (b) Cells are composed of highly independent and randomly interacting components.
    (c) Virchow stated that cells arise from pre-existing cells.

(d) The cell theory was proposed by Robert Hooke.

MULTIPLE CHOICE QUESTIONS

(1) Tubulin occurs in (a) Microtubules (b) Cilia and flagella (c) Microvilli (d) Both (a) and (b). *(Bihar PMT 2001)*

(2) Microtubules do not occur in (a) Mitochondria (b) Centrioles (c) Spindle fibres (d) Flagella. *(CBSE 2001)*

(3) The term nucleolus was coined by (a) Flemming (b) Bowman (c) Fontana (d) Strasbuger. *(AFMC 2001)*

(4) Ribosomes are granules formed of (a) rRNA + tRNA (b) mRNA + tRNA (c) rRNA + proteins (d) mRNA + proteins. *(HP PMT 2001)*

(5) Lysosomes take part in (a) Intracellular digestion (b) Extracellular digestion (c) Fat breakdown (d) Both (a) and (b). *(MP PMT 2001)*

(6) Lipid molecules of plasma membrane occur (a) Parallel (b) Scattered (c) Alternately (d) In series. *(CPMT 2002)*

(7) Chromosome carrying centromeres at one end is (a) Metacentric (b) Submetacentric (c) Acrocentric (d) Telocentric. *(AIIMS 2002, MPPMT 2002)*

(8) Which one is present nearest to plasma membrane (a) Middle lamella (b) Primary wall (c) Secondary wall (d) Tonoplast. *(AFMC 2002)*

(9) Plasmodesmata take part in (a) Synchronous mitotic divisions (b) Cytoplasmic streaming (c) Movements of substances between cells (d) Locomotion in unicellular organisms. *(AIIMS 2003)*

(10) Welded areas between adjacent cells are (a) Desmosomes (b) Gap junctions (c) Intercellular bridges (d) Inter digitations. *(CET Chd. 2003)*

(11) Chlorophyll occurs in chloroplast (a) Inner membrane (b) Thylakoid membranes (c) Outer membrane (d) Stroma. *(CBSE 2004)*

(12) Which is common in plant and animal cells (a) Centrioles (b) Central vacuole (c) Mitochondria (d) Plastids. *(DPMT 2004)*

(13) Ion connected with forming cross bridges is (a) Na^+ (b) Ca^{2+} (c) K^+ (d) None of the above. *(Orissa 2004)*

(14) Which is not a function of vacuole in plant cell ? (a) Formation of H_2O_2 (b) Waste disposal (c) Cell elongation (d) Storage. *(Pb PMT 2005)*

(15) Arrangement of ciliary microtubules is (a) 9 + 9 (b) 9 + 3 (c) 9 + 4 (d) 9 + 2. *(RPMT 2006)*

(16) A clear zone around Golgi appratus is zone of (a) Separation (b) Transition (c) Inclusion (d) Exclusion. *(CET Chd. 2006)*

(17) Lysosomes are produced by (a) Mitochondria (b) Endoplasmic reticulum (c) Golgi bodies (d) Leucoplasts. *(BHU 2007)*

(18) Which does not occur in cell membrane (a) Glycolipids (b) Proline (c) Phospholipids (d) Cholesterol. *(CBSE 2007)*

(19) Subunits of 80S ribosomes are (a) 40 s (b) 60 s (c) 40 s and 60 s (d) None of the above. *(DPMT 2008)*

(20) Vacuole of plant cells (a) lacks membrane, contains water and excretory substances (b) is membrane bound, contains water and excretory substances (c) is membrane bound, contains storage proteins and lipids (d) lacks membrane and contains air. *(CBSE 2008)*

(21) What is true of membrane lipids and proteins ? (a) None can flip-flop (b) both can flip-flop (c) proteins can flip-flop but lipids cannot (d) lipids can rarely flip-flop but proteins cannot. *(CBSE 2008)*

(22) Middle lamella is mainly composed of (a) Calcium pectate (b) Phosphaglycerides (c) Muramic acid (d) Hemicellulose. *(CBSE 2009)*

(23) Cytoskeleton is made of (a) Callose deposits (b) Cellulose microfibrils (c) Proteinaceous filaments (d) Calcium carbonate granules. *(CBSE 2009)*

(24) Who first saw and described a live cell (a) Matthias Schleiden (b) Theodore Schwann (c) Anton von Leeuwenhock (d) Rudolf Virchow. *(HP PMT 2010)*

(25) Plasma membrane consists mainly of (a) Proteins embedded in a phospholipid bilayer (b) Protein embedded in a polymer of glucose molecules (c) Proteins embedded in a carbohydrate bilayer (d) Phospholipids embedded in protein bilayer. *(CBSE 2010)*

(26) Structural element of chromatin is (a) histone (b) acid protein and DNA (c) nucleosome (d) nucl matrix. (WB 20

(27) Animal cells do not possess (a) plasmodesmata (b) centriole (c) 80S ribosomes (d) all the above (MP PMT 20

Assertion and Reason Type Questions

(1) **Assertion :** A cell membrane shows fluid behaviour.
Reason : A membrane is a mosaic of tipids and proteins.
(A) (B) (C) (D) (AIIMS 200

ANSWERS

True & False

60. (a) —F (b) —F (c) —T (d) —F

Multiple Choice Questions

(1) —d (2) —a (3) —b (4) —c (5) —d (6) —a (7) —d (8) —c (9) —a (10) —
(11) —b (12) —c (13) —b (14) —a (15) —d (16) —d (17) —c (18) —a (19) —c (20) —
(21) —d (22) —a (23) —c (24) —c (25) —a (26) —c (27) —a

Assertion and Reason Type Questions

1. —A